THE UNIVERSITY OF ALBERTA

EXAMINATION OF THE RESPECTIVE MERITS OF THREE METHODS OF REMOTE SENSING

BY

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF GEOGRAPHY

EDMONTON, ALBERTA

SPRING, 1972

ABSTRACT

In this thesis, the feasibility of using color and false color aerial photography and thermal infrared line scanning data over an agricultural area to delineate areas of potential interest is discussed. The equipment assembled for this study includes a thermal infrared line scanner, a 9 x 9 aerial camera, a computer based analogue to digital conversion, and the logistic support systems. Determination of potential usefulness is made by interpreting the colour, false colour, and thermal scanning data taken for an agricultural area near Calgary, and comparing each medium as to ease of interpretation and amount of information that can be obtained. Three computer programs which increase the ease of interpretation of the thermal infrared line scan data are presented. Each program presents the thermal output in a different format; single symbol, overprint, and isotherms drawn by the Calcomp plotter. The conversion from apparent to real temperature is discussed along with the measurements that would be required to incorporate this as a part of the program series.

It is felt that "Remote Sensing" as a way of observing a large area in a short period of time from a distance is of great potential use. However, more ground work and development of interpretation methods are required before "Remote Sensing" will develop beyond its present subjective bounds.

ABSTRACT

In this thesis, the feasibility of using color and false color aerial photography and thermal infrared line scanning data over an agricultural area to delineate areas of potential salinity is discussed. The equipment assembled for this study includes a thermal infrared line scanner, a 9 x 9 aerial camera, a computer based analogue to digital conversion, and the in-flight support systems. Determination of potential salinity is made by interpreting the colour, false colour, and thermal scanning data taken for an agricultural area near Calgary, and comparing each method as to ease of interpretation and amount of information that can be obtained. Three computer programs which increase the ease of interpretation of the thermal infrared line scan data are presented. Each program presents the thermal output in a different format: single symbol, contouring, and isotherms drawn by the Calcomp plotter. The correlation from apparent to real temperature is discussed along with the measurements that would be required to incorporate this as a part of the program series.

It is felt that "remote sensing" as a way of observing a large area in a short period of time from a distance is of great practical use. However, more ground work and development of interpretation methods are required before "remote sensing" will develop beyond its present subjective levels.

DEDICATION

This thesis is dedicated to CF-VLO. Without its help this thesis would never have left the ground.

ACKNOWLEDGEMENTS

I wish to express my gratitude to the following people and organizations for their unfailing cooperation in this endeavor:

Professor Keith D. Hage for his continuing interest, his many constructive suggestions, and, in particular, for his help in editing this manuscript.

Dr. Robert M. Holmes and the Canadian Department of Environment for providing use of the required equipment and the subsequent data for the Dalemead test area.

Dr. John M. Powell of the Canadian Forestry Service for providing the data of the Hinton test area.

Dr. John L. Honsaker and Mr. Dennis Oracheski for their aid in programming the Nova 1200, use of which was offered by the Institute of Earth and Planetary Physics.

Dr. W. A. Davis and Mr. Rod McPherson for their aid in writing the programs for the University of Alberta's IBM 360.

Mrs. Kathryn A. Lubitz for her aid in operating the thermal infrared line scanner and the field printer, and for typing the rough draft.

Mrs. Laura Smith for typing the final draft of this manuscript.

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CHAPTER I

BACKGROUND

1. Introduction

In the face of the growing demands on the earth's resources, it is becoming increasingly important to be able to ascertain the physical processes operating over large areas of the earth's surface. In order to facilitate this, various methods of remote sensing of the earth's surface from aircraft or other mobile platforms have been developed. This thesis concerns itself with possible uses of three specific remote sensing mediums, each using a different portion of the electromagnetic spectrum. The first two are closely related and deal mainly with reflected energy in the visible light range; the third senses emitted energy in the form of heat. All three have their advantages, disadvantages, and limitations which must be understood before the optimum use of each may be achieved.

The three methods of remote sensing discussed within this thesis are based upon the electromagnetic spectrum which is a continuum consisting of the ordered arrangement of radiation according to wavelength, frequency, or photon energy. It has been established both experimentally and theoretically that the electromagnetic spectrum includes waves of every length from nanometers to kilometres. There is no "all-spectrum" detection device, so, by necessity, the spectrum has been somewhat arbitrarily separated into

various spectral regions. (See Table 1)

This thesis in particular deals with the possible use and interpretation of colour film, infrared false color film, and thermal infrared line scan data presented on film and on IBM 360-67 computer output. In interpreting the data, attention was directed towards the potential of each method as well as to actual observations and the details of what was observed.

Because infrared techniques are particularly well adapted to observation from a distance, it is not surprising to find them widely used. The term "remote sensing" has recently become fashionable and its practioners have tried hard to sell it as a new technique. Lord Rosse made the first radiometric determination of the moon's temperature in 1869, (Hudson, 1969) and astronomers and astrophysicists have attached radiometers to their telescopes ever since, to gather information on the universe by remote sensing techniques. Before we begin the discussion of the electromagnetic spectrum, it would be beneficial to look quickly at some of the possible applications of infrared imagery as outlined by J. D. Hudson in his book *Infrared System Engineering*.

One of the major nonmilitary applications of infrared techniques is the use of infrared instrumentation for meteorological observations from satellites. These applications include determination of the solar constant, measurement of reflected solar radiation, analysis of the earth's heat budget, study of day and night cloud cover, location of weather fronts, determination of atmospheric structure and temperature profiles, measurement of the altitude of cloud tops, determination of land and sea-surface temperatures, and

TABLE 1

ELECTROMAGNETIC SPECTRUM FOR REMOTE SENSING

Kinds of Waves	Wavelength (CM)	Frequency	Usual Method of Detection
X-rays	10^{-7}	3×10^{17}	Fluorescence, Chemical effect, Ionization, NaI crystals
Ultra-violet	10^{-5}	3×10^{15}	Fluorescence, Chemical effect
Light	$39\text{-}78 \times 10^{-6}$	$77\text{-}38 \times 10^{13}$	Eye, Chemical effect, photodetectors
Infrared	63.28×10^{-6} 751×10^{-4} to 1×10^{-1} $31.25\text{-}27 \times 10^{-6}$	47.3×10^{13} 4.34×10^{13} to 300 GHz	Laser Thermopile, Bolometer Radiometer, Photo-detector
Microwaves	1-0.1	30-300 GHz	Diodes Bolometers

Source: American Geological Institute, 1968

the analysis of ocean circulation patterns.

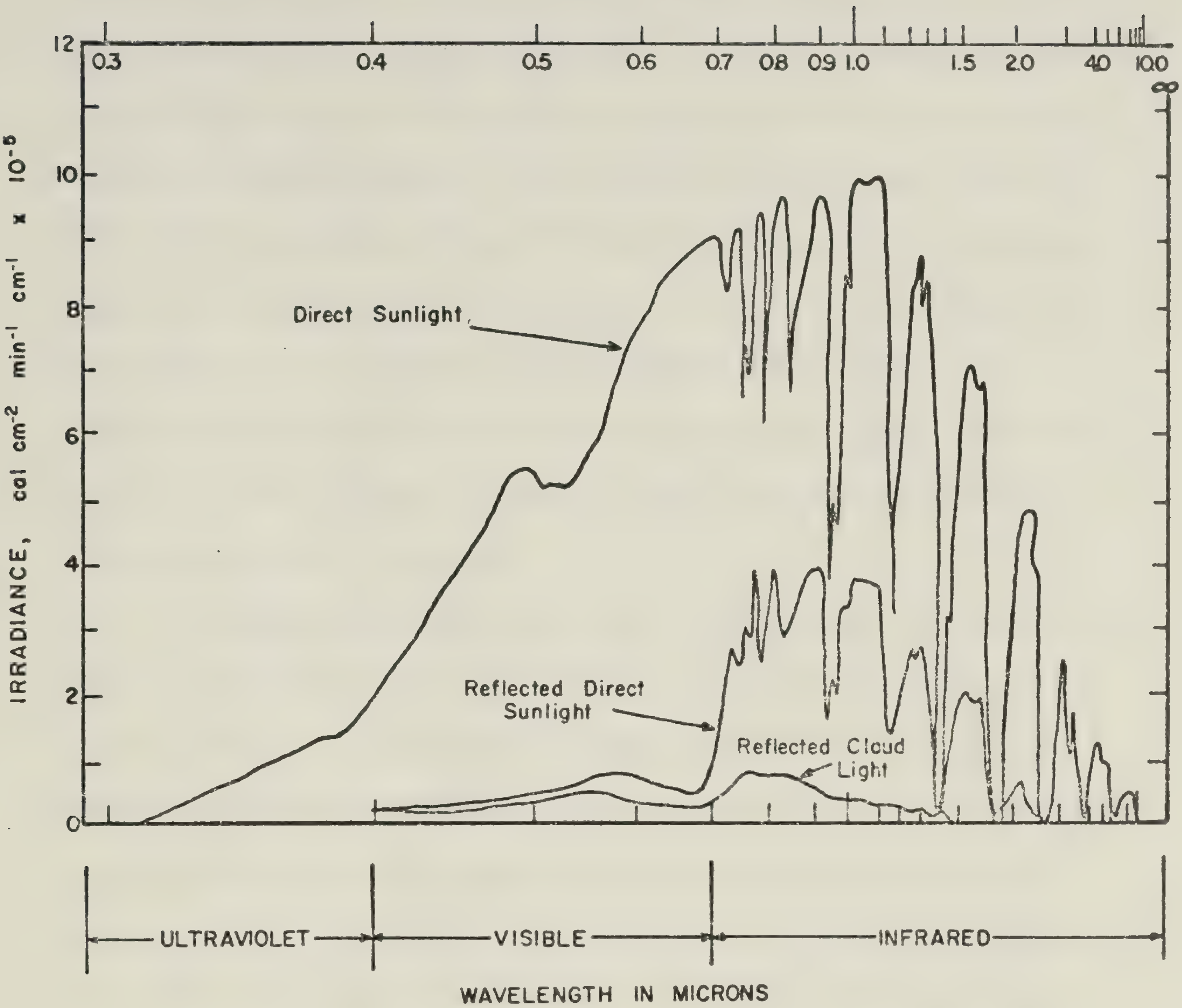
Remote sensing spectroradiometers can be used to measure the spectral radiant emissivity and reflectivity of agricultural ground cover. The output is used to identify crops, assess crop damage, and classify soils. Ecologists are studying the thermodynamic environment in which we live by use of infrared thermometry. Non-contact measurement permits scientists to study the heat adaptation of plants and animals in a changing thermal balance.

Detection and measurement of air pollutants is another vital role that is performed by infrared instruments. Pollutants emitted by industrial plants can be monitored day or night. An exhaust analyser can instantly measure the percentage of carbon monoxide and parts per million of hydrocarbons emitted by the internal-combustion engine.

2. Solar Spectrum

The sun is the primary souce of energy for remote sensing. Radiation from the sun is attenuated by the earth's atmosphere and selectively reflected by terrestrial features. Wavelengths of importance in transferring energy from the sun to the earth's surface range from 0.3 μm to 4.0 μm. This range overlaps the colour and infrared false colour film sensitivities of 0.4 μm to 0.7 μm and 0.5 μm to 0.9 μm respectively.

The curve for reflected direct sunlight from a Western Cottonwood (Populus deltoides) leaf, for example, peaks at a point slightly below 0.6 μm in the green region of the spectrum (see Fig. 1, Hunter et al., 1970). For photography sensitive to visible light, the



CRITICAL TERRAIN ANALYSIS

Figure 1. The spectral distribution of direct sunlight incident on a horizontal surface. Also shown in the spectral distribution of reflected direct sunlight and of reflected cloud light from a Populus Deltoides leaf. (Hunter, et al., 1970)

leaf will appear green. In the near infrared region of the spectrum much more reflected energy is available. If uniform overcast conditions exist, most of the reflected light from a leaf will diffuse. The spectral distribution of this energy is shown by the curve for reflected cloud light in Fig. 1. Note that the ratio of reflected energy in the photographic infrared (0.5 μm to 0.9 μm) to that in the 0.4 μm to 0.7 μm range of the visible light is greater for reflected direct sunlight than for reflected cloud light. Therefore, it would be more difficult to obtain proper exposure of infrared film under overcast conditions.

Diffuse solar radiation results when direct solar energy is scattered and reflected by water vapour and the particulate matter in the atmosphere. Scattering depends on the particle radius of inhomogeneities in the medium relative to the wavelength of interest. For very small particles, scattering will vary inversely as the fourth power of the wavelength penetrating the medium (Rayleigh's law). Thus, this type of scattering is reduced with longer wavelengths. However, as the particle size increases to the order of 1/10 to 10 wavelengths, Mie scattering begins to predominate (Jensen, 1968) with maximum scattering occurring when the wavelength is equal to the particle radius. Large solid particles (greater than 10 wavelengths) result in non-selective scattering or reflection of light with all wavelengths being affected equally.

If the particles causing scattering are submicron in size, such as smoke or haze, the use of infrared photography will result in greater image contrast than will the use of colour photography because of lowered scattering, resulting from the sensitivity of

infrared film to longer wavelengths than the colour film.

The energy received at the earth's surface, and thus the total energy available to expose the photographic medium, will depend on the solar altitude. As the solar beam forms a greater angle with the zenith, the pathlength through the atmosphere lengthens, and the total available energy decreases and the ratio of direct to diffuse solar radiation reaching the earth's surface increases. Thus, with increased geographic latitude, there will be a relative increase of diffuse solar radiation and a decrease of direct solar radiation. Therefore, given the same terrain subject, total reflectivity will vary with geographic latitude. As a result, a slightly different filtration and total camera exposure will be required in the Arctic as opposed to a temperate climate to compensate for the spectral difference in composition of the incident solar radiation. To illustrate this effect, Fig. 2 shows the variation in attenuation of the solar energy received at the earth's surface for a number of different pathlengths of the solar beam through the atmosphere. M, the optical air mass, is a measure of the pathlength of the solar beam through the atmosphere, expressed as a multiple of the pathlength to sea level for a source at the zenith. Note that as the air mass increases, the spectral distortion of the maximum incident energy increases from 0.47 μm to 0.69 μm for M = 0 and M = 5 respectively.

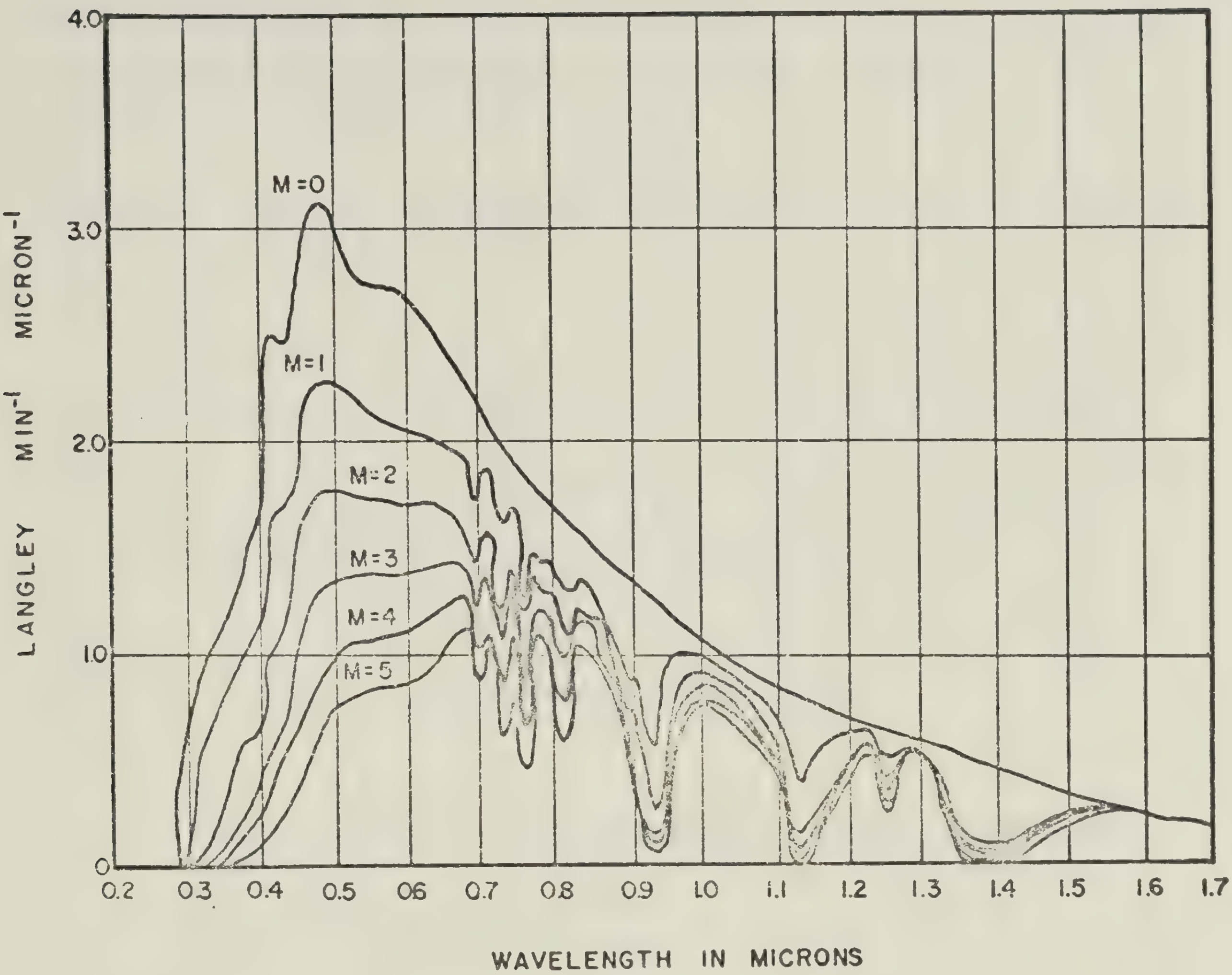


Figure 2. Spectral distribution of solar radiation incident on a normal surface for six optical air masses. (Moon, 1940)

3. Electromagnetic Radiation

The portion of the electromagnetic spectrum that is of special interest to this study is indicated in Fig. 3. All radiation obeys similar laws of reflection, refraction, diffraction, and polarization. The velocity of propagation is the same for all radiation. One type of radiation differs from another only in wavelength and frequency.

The infrared region is bounded on the long wavelength side by microwaves and on the short wavelength side by visible light. Since objects at the earth's temperature radiate energy primarily in the infrared region, it is often referred to as the heat region of the spectrum. The nomenclature used here is compatible with a standard terminology suggested by Ballard (1959).

Designation	Abbreviation	Limits (micrometers)
Near infrared	NIR	0.75 to 3
Middle Infrared	MIR	3.00 to 6
Far Infrared	FIR	6.00 to 15
Extreme Infrared	XIR	15.00 to 1,000

Since all types of radiation shown in Fig. 3 are considered to be forms of wave motion, they must obey the general equation:

$$\lambda v = c \qquad (1)$$

where λ is the wavelength, v is the frequency, and c the velocity.

According to Kirchoff, when an object is at thermal equilibrium, the amount of absorptivity α, will equal the amount of

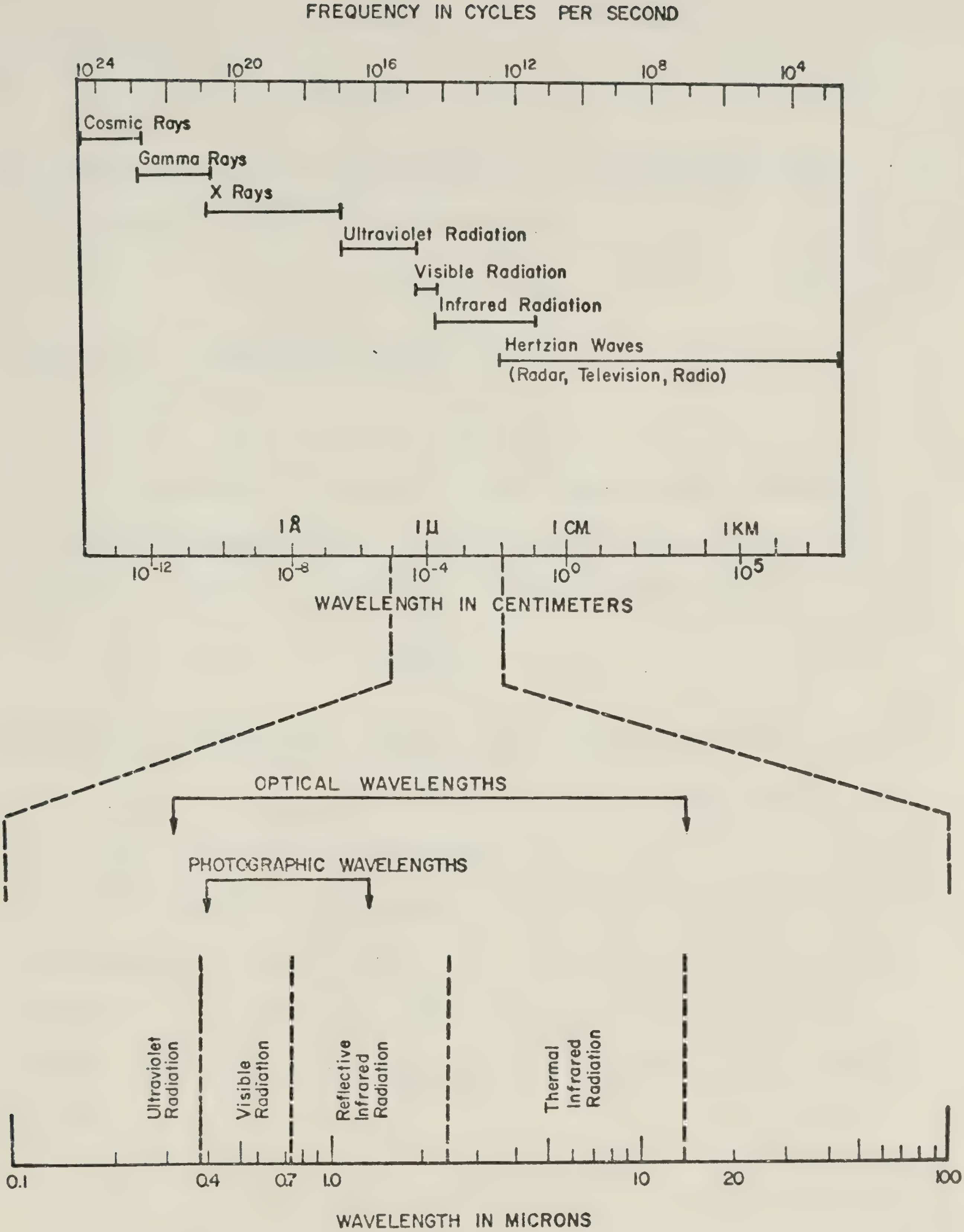


Figure 3. The electromagnetic spectrum with emphasis on the region of primary interest to this study. (LARS, 1970)

emission ε:

$$\alpha = \varepsilon . \quad (2)$$

The sum of absorption, α, reflectivity, p, and transmissivity, λ must equal all of the total incident energy:

$$1 = p + \alpha + \lambda . \quad (3)$$

Therefore, by substitution from Eq. (2):

$$\varepsilon = 1 - (p + \lambda) .$$

Emissivity is the ratio of the radiant energy emitted by an object at a temperature, T, to the radiant energy emitted by a blackbody at the same temperature, T. This may be written as:

$$\varepsilon = \frac{W_o}{W_{bb}} \quad (4)$$

where W_o equals the total radiant energy emitted by an object at a given temperature, W_{bb} equals the total radiant energy emitted by a blackbody at the same temperature.

An ideally radiating body or surface re-radiates all electromagnetic radiation (EMR) that it receives. However, all real objects emit less than this theoretical maximum. The amount of emission is given by Stefan-Boltzmann's Law (Bernard, 1970). (See Fig. 4.)

$$W = \varepsilon r T^4 \quad (5)$$

where W is the specific intensity (Watts cm^{-2}), k is Boltzmann's constant (5.67×10^{-12} W/cm^2K^4), T is absolute temperature, and ε is emissivity.

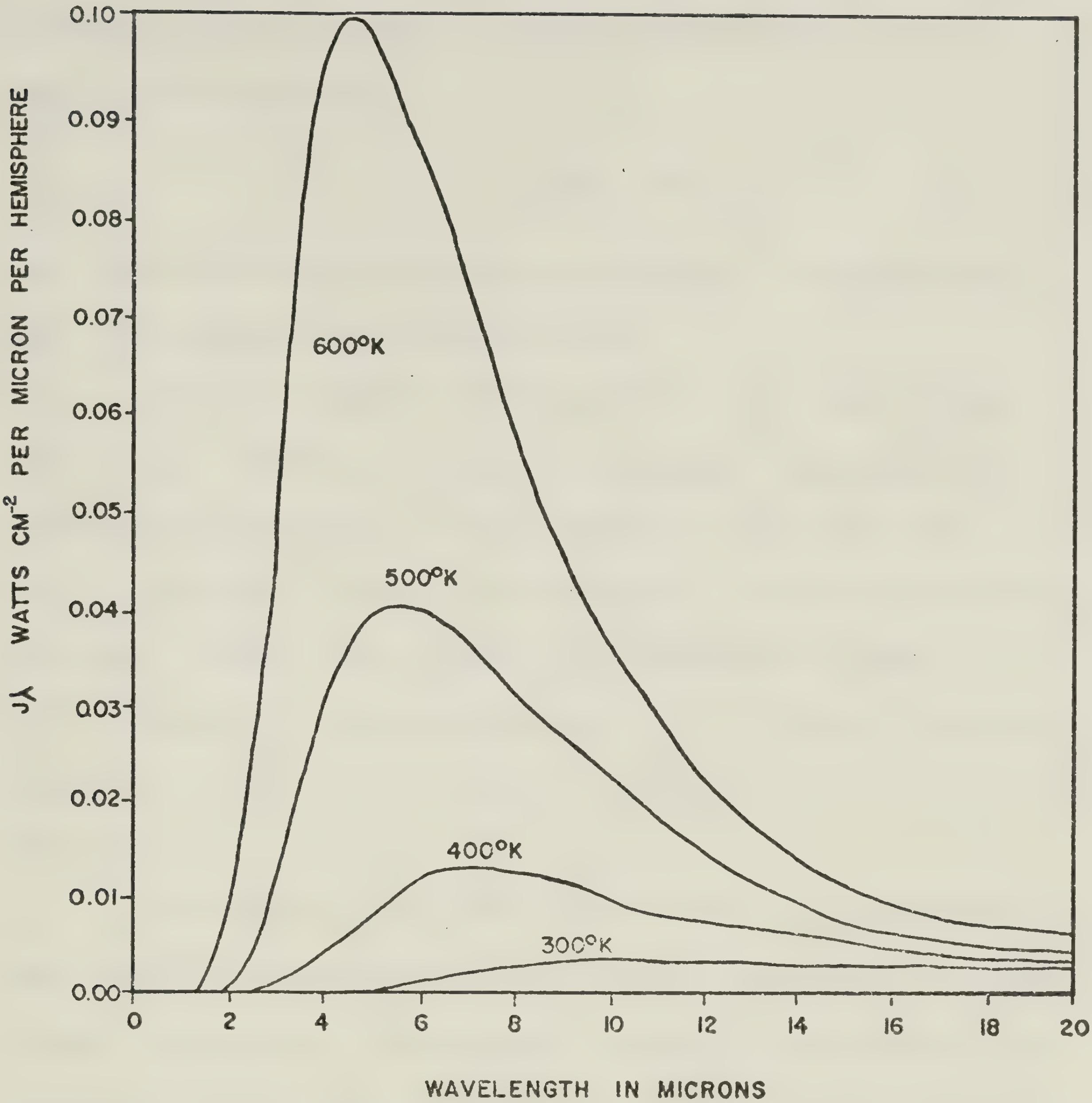


Figure 4. Spectral distribution of energy for perfect emitters at various temperatures. (American Geological Institute, 1968)

According to Wien's displacement law the wavelength at which the maximum amount of energy is emitted becomes shorter as the temperature is increased.

$$\lambda \max = 2.89 \times 10^3 \ \mu m \ k/T \qquad (6)$$

where $\lambda \max$ equals the maximum energy wavelength in microns and T equals the temperature in degrees Kelvin.

The EMR is produced by the motion of the various charged particles that make up the atoms. The frequency and intensity of the EMR depends primarily on the temperature of the body; this is termed a first order effect. The emissivity, or deviation from the theoretical maximum amount of EMR that a substance can emit at a given temperature, is controlled chiefly by the chemical composition and physical state of the substance, and may be considered a second order effect.

The surface of the earth, when heated by the absorption of solar radiation, becomes a source of longwave radiation, particularly infrared wavelengths. The atmosphere is nearly transparent to visible light radiation, but it readily absorbs the longwave terrestrial radiation. The principle atmospheric absorbers are water vapor (5.3 μm to 7.7 μm and beyond 20 μm), ozone (9.4 μm to 9.8 μm), carbon dioxide (13.1 μm to 16.9 μm), and clouds (all wavelengths). Only about 9 per cent of the terrestrial radiation escapes directly to space, mainly through the "atmospheric windows" (Sellers, 1965). The atmospheric windows occur at two IR bands, 3.5 μm to 5.5 μm and 8 μm to approximately 14 μm. (See Fig. 5.) These are the bands within which the line scanner operates.

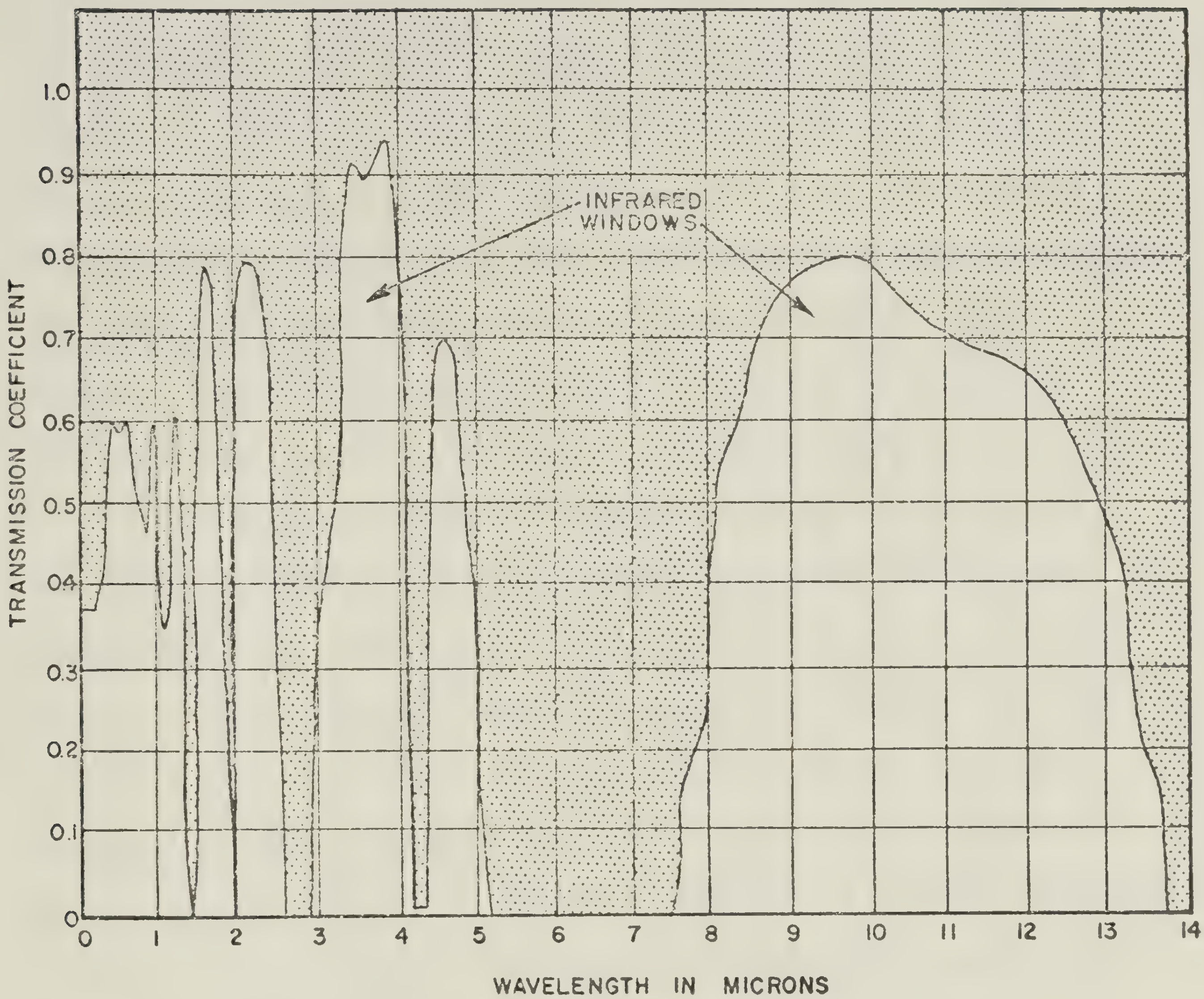


Figure 5. Transmission spectra of the atmosphere. (American Geological Institute, 1968)

To gain an impression of how strong diurnal effects can be, refer to Fig. 6, which shows continuous thermocouple measurements for a number of materials over one complete 24-hour period near Ann Arbor, Michigan, in June 1963 (National Academy of Science, 1970). A number of things are immediately apparent; first, just before dawn, a quasi-equilibrium was established, e.g., the slopes of the curves are very small in most cases; after dawn, this quasi-equilibrium was upset. All materials warmed up differently and the curves crossed. Peak temperatures were reached shortly after noon; the reverse process occurred during the afternoon and evening.

Notice particularly the temperature curve for water. It was distinctly different from the others in at least two features. The maximum daily temperature variation was significantly less than any of the other materials shown. It reached its maximum temperature an hour or two after any of the other materials shown. This is explained in terms of absorbtivity and emissivity of water and its very large heat capacity in comparison with most of the other materials. Because of this behaviour, the other temperatures will usually swing above water during the day and below it during the night.

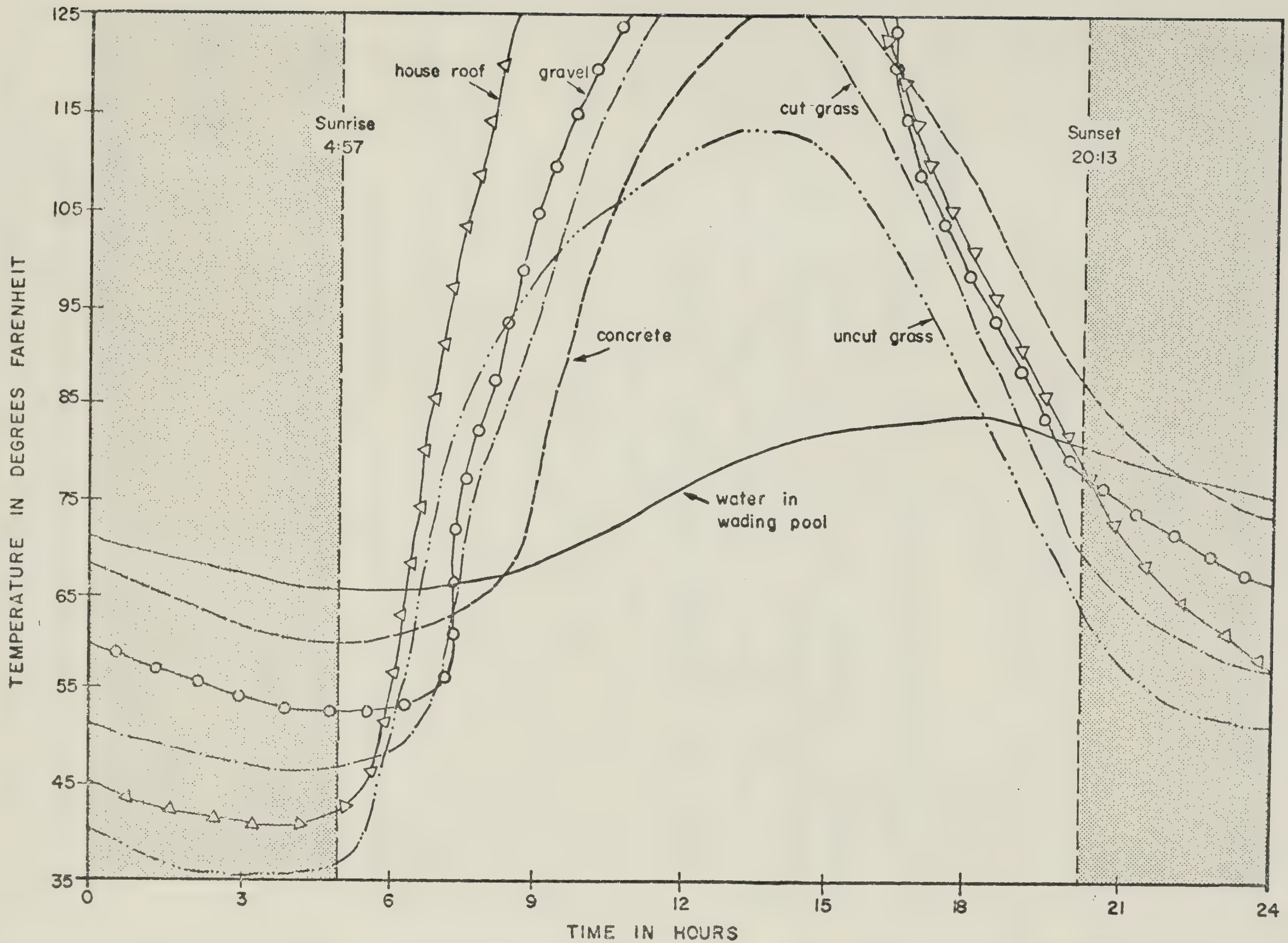


Figure 6. Diurnal temperature fluctuations. (National Academy of Sciences, 1970)

CHAPTER II

LITERATURE REVIEW

1. Introduction

This literature review attempts to outline the current state of research within the field of Remote Sensing. The approach is to outline in several subsections how a researcher approached a specific problem and which tools of Remote Sensing will give him the best results. The review is by no means extensive. Its primary purpose is to outline current work and to establish a preliminary background for anyone wishing to do further work.

The literature that pertains to the infrared can be divided into two categories, the published and the unpublished. In more practical terms these might be called the "readily available" and the "not so readily available" literature. The subject is weighed down by a huge volume of partly classified, unpublished literature, and I have had to use the literature that is available, which is published.

2. Terrain Characteristics

The spectral reflectance curves for various terrestrial subjects are illustrated in Fig. 7. It should be noted that a large number of the terrain features are tightly grouped with a low reflectance in the visible, but the reflectance curves are more

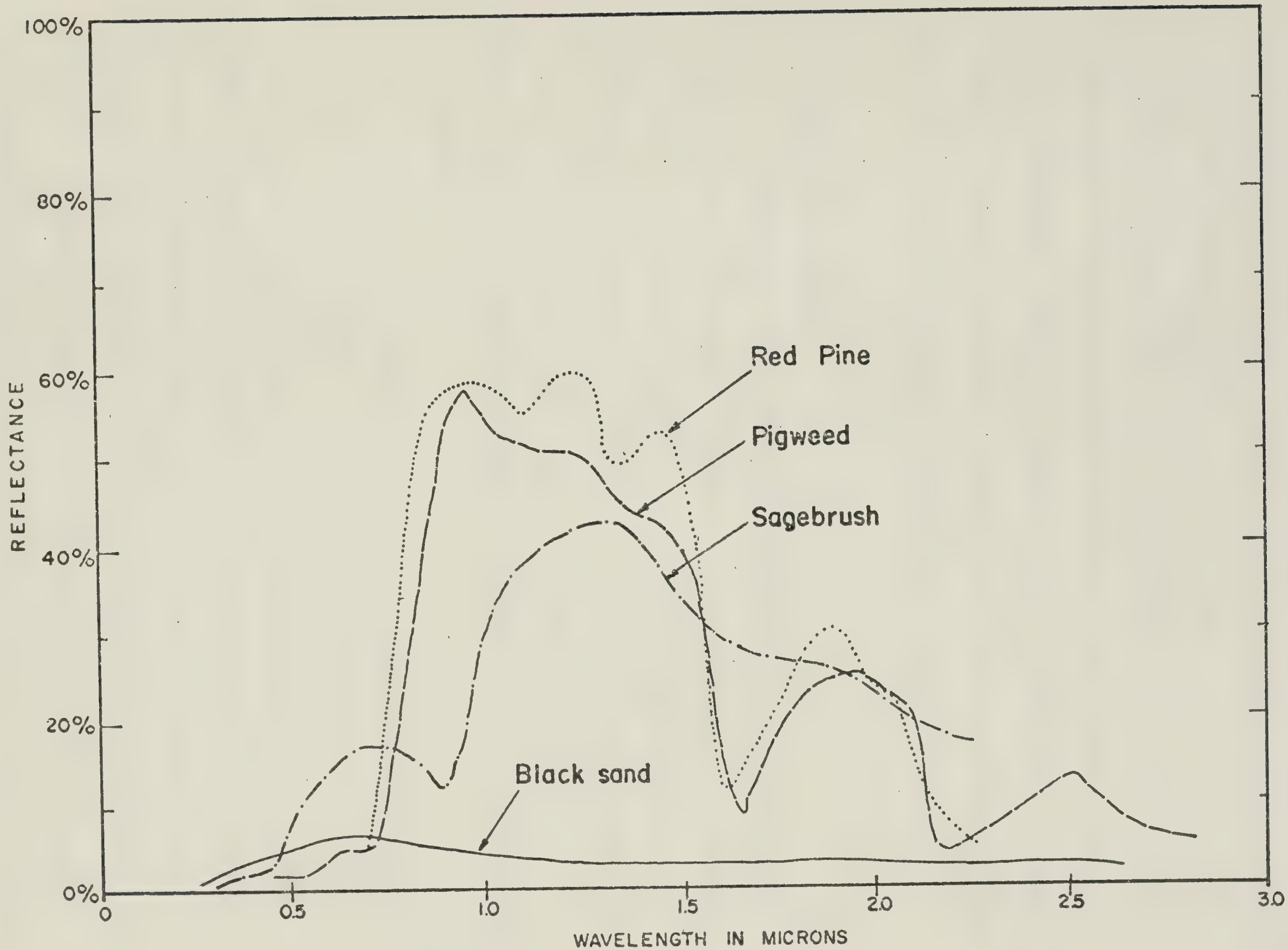


Figure 7. Spectral reflectivity curves (Miller, 1969).

evenly distributed with less overlap in the near infrared portions of the spectrum (0.7 μm to 0.9 μm). Thus, it will be easier to record these features with greater tonal differences on infrared film than on colour film. For the purposes of discussion of the applications of colour and infrared false colour films to terrain data acquisition, the earth's surface may be divided into a number of general categories which have similar scene characteristics. These categories include vegetated surfaces, bare soils and rocks.

3. Vegetated Surfaces

Vegetation covers most of the habitable portions of the earth's surface and greatly influences the uses which can be made of the land. Consequently, there is a need for detailed, accurate information as to the kind, density, and distribution of vegetation throughout large land areas. Remote reconnaissance with remote sensors provides a promising means of obtaining much of this needed information.

For nearly a century photographic emulsions sensitive to energy in the visible part of the spectrum have been successfully used by aerial photo interpreters in mapping vegetation as to type, vigor, and density. In recent years, through the use of special film-filter combinations which exploit carefully selected segments of the visible, ultraviolet, and photographic infrared portions of the electromagnetic spectrum, the usefulness of aerial photography in vegetation analysis has been further increased. However, many of the diagnostic features that are potentially useful to the vegetation

analyst cannot be discerned on any such photography.

The following factors have been observed to affect reflectance in forests (Reifsnyder, 1965). Young foliage of spruce and fir have 3 to 4 times greater reflectance than older foliage. For deciduous trees, older leaves reflect more than the younger leaves. The reflectance from hardwood foliage decreases during the early weeks of the growing season, remains constant until mid or late summer, and rises rapidly during the autumn colour change. At the same time, variations in reflectance from the foliage are minimized during autumn. The reflectance from conifers decreases significantly towards the end of the growing season. The drier the habitat, the greater is the leaf reflectance in the visible spectrum. Infrared reflection tends to decrease strongly with increasing altitude. Increased fertility of the soil reduces the reflection in ash and oak. Climate and geographic location in latitude influences the properties of leaves. Arctic, temperate and tropical leaves are all very different from each other.

If one is to understand why vegetation registers in different tones in different spectral bands, one needs to apply the considerations discussed previously to the leaves that are exposed to the aerial view at the time of remote aerial reconnaissance. Fig. 8 shows in diagrammatic form the cross-section of a healthy green leaf. It is designed to emphasize the following pertinent points:

(a) In the visible part of the spectrum one is concerned primarily with energy that is reflected from the leaf, and since reflectance in this part of the spectrum is governed by the characteristics of chlorophyll, one is

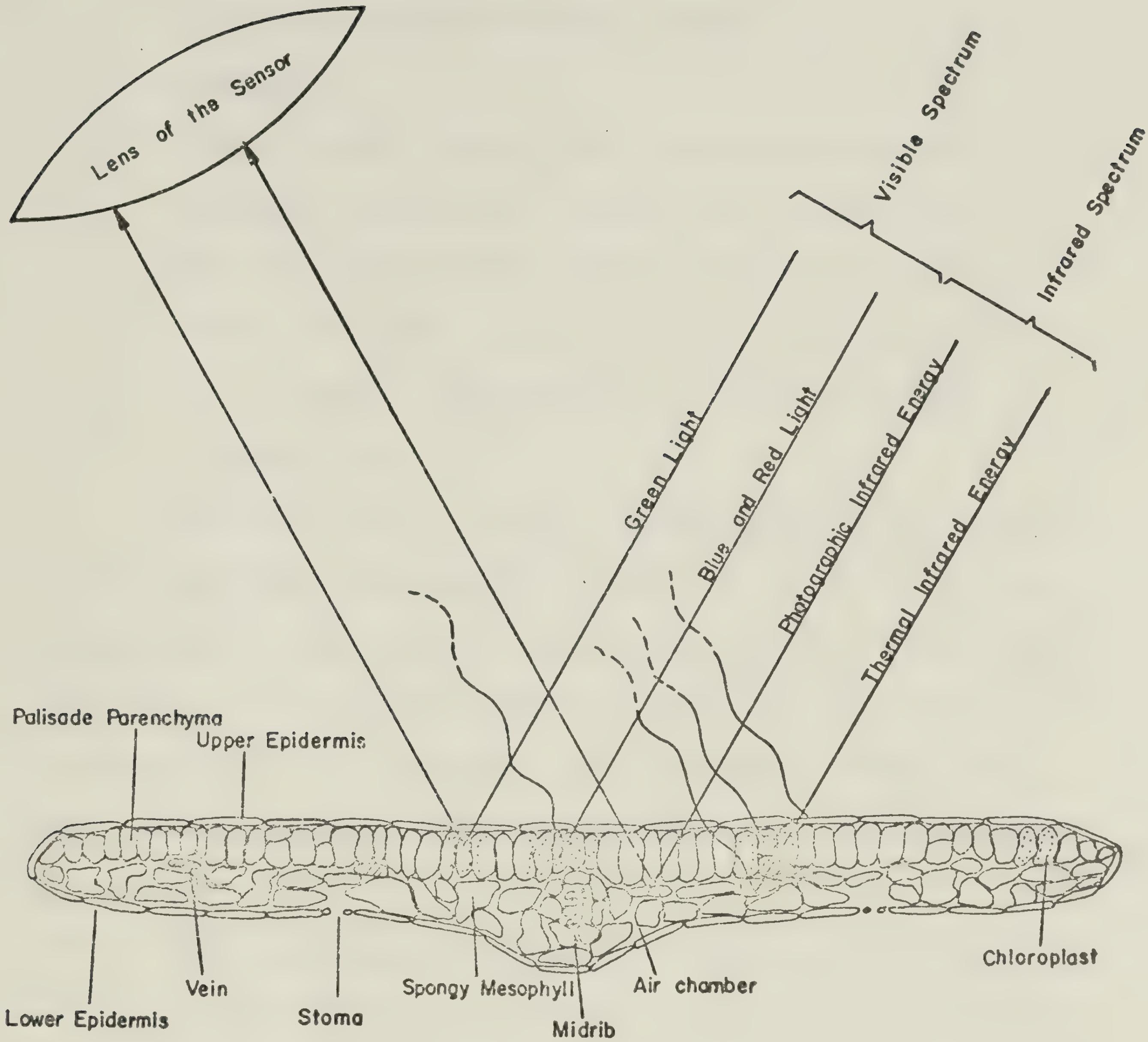


Figure 8. Cross-section of a leaf of a typical broadleaf plant showing the response to incident energy in various spectral zones. (Colwell, et al., 1966)

dealing primarily with photochemical relationships.

(b) In the photographic infrared part of the spectrum one is concerned with structural characteristics of the mesophyll.

(c) In the thermal infrared part of the spectrum one is concerned primarily with energy that is emitted from the entire leaf, and the rate of emission is governed by both the leaf's inherent emissivity characteristics and its absolute temperature at the time of sensing (Colwell, 1966).

The temperature of a leaf at any given time is an indication of its response and adjustment to the heat load imposed upon it by its environment (Gates, 1963). One important factor affecting leaf temperature is transpiration, the process by which leaves lose moisture through stomatal openings in the epidermal tissues (Gates, 1964). Leaves transpiring readily may be as much as 5°C cooler than nontranspiring leaves.

Many insects and disease attacks cause disruption of the water metabolism of the host trees by plugging or severing the water and solute conducting tissues. Trees subjected to such attacks become less vigorous and their foliage develops higher moisture tensions than unaffected trees. Weber and Olsen, 1967, found that under high moisture stress, trees were consistently warmer by 2-5°C than control trees under low moisture stress. In several instances light reflectance characteristics of leaves which develop with ample water are not greatly affected by increasing moisture stress, whereas leaves which develop under periods of high moisture stress are

significantly less reflective at all wavelengths than leaves which develop with ample water.

Thermal measurements made on different kinds of foliage indicate that nearly 90 per cent of the total heat load on a leaf is contributed by direct solar insolation; the remainder is provided by thermal infrared radiation that is emitted by the atmosphere, the ground, and the surrounding vegetation. Various kinds of chemical activity taking place within leaves through such processes as photosynthesis, an energy absorbing process, and respiration, an energy emitting process, are recognized by Gates (1964) as playing only minor roles. Usually about 70 per cent of the radiation load on the leaf is dissipated through re-radiation. It is this re-radiated energy that is captured when obtaining thermal infrared imagery by remote aerial reconnaissance. Throughout the daylight hours, transpiration exerts a far greater cooling effect on the foliage than does convection, so long as the surrounding atmosphere is nearly motionless. If the wind velocity increases to a mere 2 to 3 miles per hour, the resulting "forced convection" may exert a far greater thermal effect on the plant than does transpiration.

Foresters can distinguish forest and non-forest land and tell something about tree height and density on a 1:20,000 photograph, but they can seldom identify individual trees accurately until colour film is used and scales approach 1:1,500 (Hellner, Doverspike and Aldrich, 1964). Boundaries of agricultural fields can be well delineated on a normal scale, 1:20,000 photograph, but crop species identification is almost impossible. Colwell (1964) found by using various combinations of filters and films that a number of crop

species responded variously in different regions of the electromagnetic spectrum. By comparing photographs of the same scene on colour, infrared false colour, infrared, and panchromatic black and white films, he could discriminate several crop species. This could also be accomplished by using a line scanner suitably filtered to record the desired portions of the spectrum.

At the time when remote reconnaissance is being conducted, if the rate of emission from the foliage is the same as from the background, the resulting imagery will exhibit a uniformly gray tone from border to border. However, the limited amount of information available in plant emission indicates the following about leaf temperature relationships: during the midday hours, fully illuminated leaves of most broadleafed species of vegetation have temperatures that average 3-5°C warmer than those of the surrounding sunlit ground; shaded leaves have temperatures which, on the average, are 3-5°C cooler than the surrounding sunlit ground; and the temperature of shaded ground, while variable, is about the same as that of shaded foliage.

In many instances the foliage of a tree is imaged, not against a background of bare soil, but against a background of lower lying vegetation such as grass or shrubs. Under such conditions, the tree foliage is likely to appear darker instead of lighter than its background on thermal infrared imagery that was taken near the middle of the day.

Ciesla (1971) reported that test plots protected by aerial sprays from forest tent caterpillars were readily discernible on both colour and false colour IR film. However, the IR film provided greater

contrast between plots with differing degrees of defoliation. The 1:15,000 photo scale was somewhat superior to the 1:6,000 because it permitted interpretation of a larger land area with a minimal loss of detail.

In determining an area containing likely sources of materials for engineering construction in a delta region (Orr, et al., 1971), false colour IR was preferred in most instances for detailed analysis. Thermal infrared provided useful information where it was applied in conjunction with the aerial photographs.

The following recommendations were put forward in LARS Research Bulletin, No. 873 (1970) regarding the use of colour and false colour IR photography. The capability of the infrared film to accurately differentiate bodies of water makes it an invaluable aid in ground water studies. In general, the colour infrared photographs taken at 1:14,000 were more satisfactory than smaller scale photos for identification of the crop types and species; a lower altitude is recommended for flight missions. For fields with a low percentage of vegetative cover, colour infrared photos are superior to colour in determining the presence of vegetation. It is extremely difficult to differentiate between completely bare soil and a low percentage of vegetative cover on colour photography. Color infrared photography is more useful than colour photography for determining the presence of bare soil as opposed to dry, dead vegetation in spot locations within a canopy of green vegetation. Conditions of crop health and maturity can best be studied using both colour and IR false colour photographs in combination. Colour photos are easier and more reliable for interpretation purposes, but more subtle differences

in spectral reflectance that would be overlooked in colour photography are often more apparent on the IR colour films. Crop canopy conditions can be grossly misinterpreted at view angles away from the nadir. Colour photos are useful for purposes of soil type and condition classification. However, in many instances colour IR photos were required to differentiate between bare soil and dead vegetation and between bare soil and fields containing recently germinated crops.

4. Bare Soils and Rocks

Bare soils tend to have a maximum reflectance variation in the 0.6 μm to 0.7 μm portion of the spectrum. This range is included in the spectral sensitivity of colour, colour infrared, and panchromatic films. This explains why panchromatic (black and white) film has proved quite satisfactory for general detail mapping. However, colour films offer greater ease of identification of soil and rock features and, consequently, the scale may be reduced. Tanguay, 1969, indicates that soil boundaries may be most accurately and easily delineated with colour film. Often a unique colour may be associated with a particular stratigraphic unit or igneous complex, and can be used as a ready horizon marker in mapping bedrock. If field checks are performed on each unit, surficial geologic maps can be prepared directly from the colour aerial photography. However, for the interpretation of landforms and parent material relationships, photographic scale is much more important than the type of photographic medium.

Infrared photography gives increased contrast between wet

and dry soil areas and is superior for the preparation of drainage maps. Similarly, infrared photography will emphasize the surface configuration and textural detail on exposed bedrock due to the presence of shadows and small amounts of moisture in bedrock depressions.

5. Ground Temperature and Thermal Infrared

According to Bastuscheck (1970) the minimum resolvable temperature difference using an infrared thermal line scanner, is a function of system parameters, and of the apparent temperature of the target being scanned. The minimum energy differences which can be presented by the imaging system as a discernible change in imagery represents a much larger temperature change in a cold target than it does in a warm target. An InSb detector exhibits much more effect than a Trimetal detector. This results not from any inherent sensitivity of the detector, but rather because of the radiant energy distribution with wavelength and the spectral bands within which the detectors are sensitive. If the average target temperature changes 70°K from 313°K to 243°K, a 10 to 1 change in ΔT occurs for an InSb detector; for the same temperature change in the target for the Trimetal detector, a change of less than 5 to 1 occurs. Further, the target portion of the change in which the Trimetal detector responds best is for a target temperature of 273°K and below. The major change for an InSb detector occurs in the temperature region above 283°K.

For thermal resolution stability in the imagery, a Trimetal detector should be used. If minor thermal detail is sought in an

area which may be cooler than its surroundings, the Trimetal is required. In general, the Trimetal detector should be used if detail is required in cold or ambient temperature areas. On the other hand, if the purpose of the imagery is to detect warmer spots in an ambient background, an InSb detector will provide the best imagery. If the target temperature is quite cold, e.g., 250°K, neither detector will provide much sensitivity. The InSb detector observes a small percentage of reflected energy when solar input is present, the Trimetal does not.

6. Discrimination of Reflected and Emitted IR

A simple consideration of the sources of reflective and thermal infrared energy will clarify the division between these two general classifications of imageable radiant energies. The sun is often taken as a 5800°K blackbody and is the direct source of the infrared energy reflected from objects on the earth's surface. Thermal infrared energy results from the self emission of these same objects heated by the sun and radiating energy as graybodies of approximately 300°K ± about 40°K. Infrared mappers will accept radiant energy from either source, reflected or emitted, interchangeably and will not distinguish between the two. Daytime thermal mapping requires that a detector-filter combination be selected which excludes the reflective energy component. It has been necessary in making such a selection to consider when the reflective energy component from a natural object, or the collection of objects, ceases to be significant when compared to the thermal component. The solar blackbody curve can be modified by the reflectivity of a

surface material and, compared with the 300°K self-emission of that same surface, modified by its emissivity taken as one minus the selected reflectivity. The point of intersection of these two graybody curves indicates the wavelength region where equal energy from both sources would be collected by the mapping system. (See Fig. 9.) Above or below this wavelength the total energy reaching the system rapidly becomes thermal or reflective in nature. The wavelength of this point of equal energy will vary depending on several factors: the surface physical properties viewed, the temperature of the surface, and the absorption of the atmosphere. The wavelength range of the equal energy points occurs within a nearly transparent atmospheric window, and so the atmospheric absorption plays only a minor role. The types of changes in environmental temperatures usually mapped range within 10°K to 20°K of a 300°K ground radiator and the associated small change in the self-emission graybody curve will not change the wavelength of the equal energy points appreciably. The most important factors controlling the location of the transition zone are the surface properties of the object imaged, namely, its reflectivity and emissivity (Miller, 1969). The intersection of a 5800°K blackbody curve modified by an average surface reflectivity of 0.9 with a 300°K graybody curve with an emissivity of 0.1 occurs at approximately 6.5 μm (Fig. 9). This might represent a full sunlight view of aluminum roofing or of water at an angle appropriate for specular reflectance. It is thus possible to image significant reflected energy from highly reflective surfaces with a 4.5 μm to 5.5 μm system. The integral of the area under each of these two curves

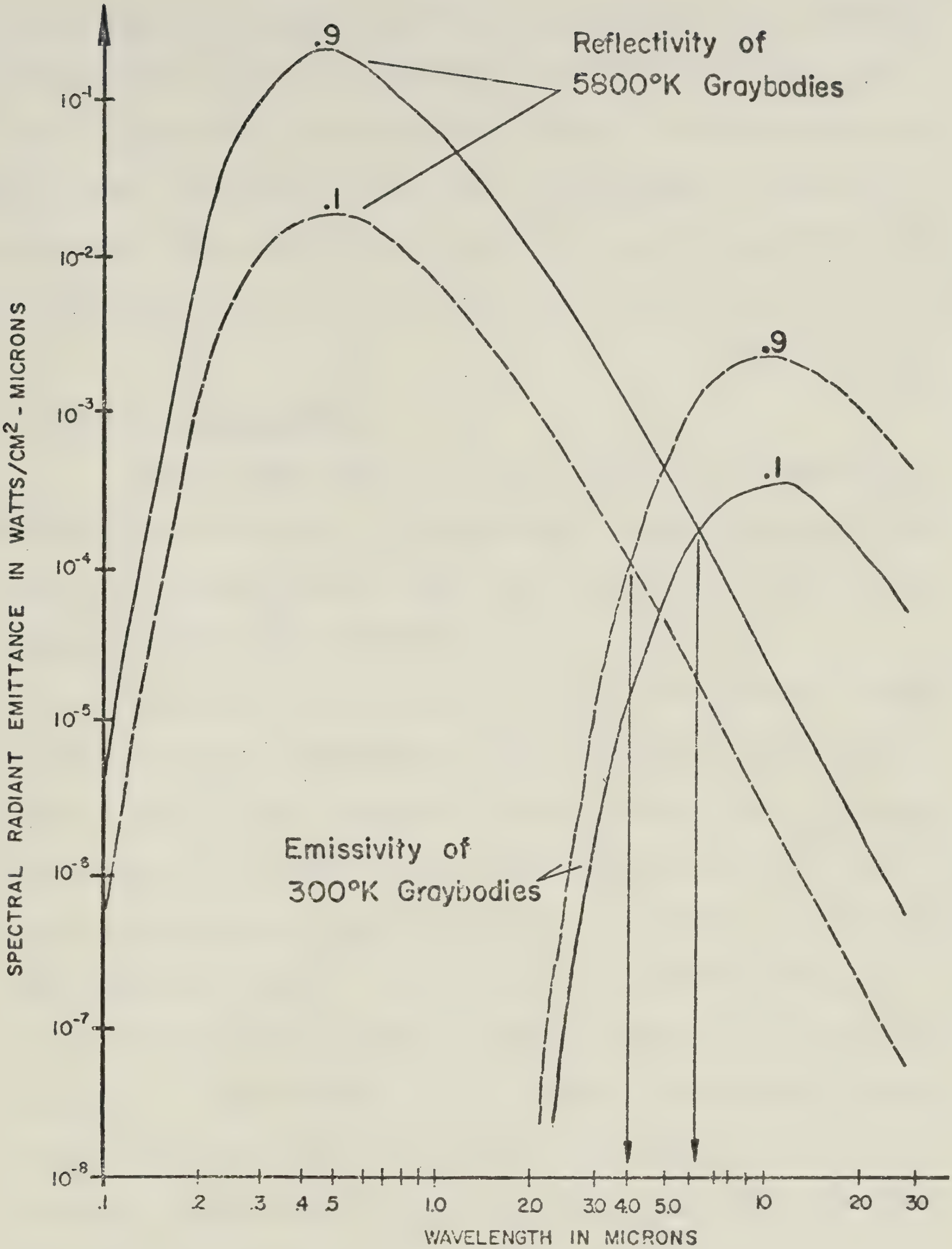


Figure 9. Solar reflection vs. surface emission. (Miller, 1969)

representing the approximate reflected and emitted energy received from an object can be taken from lower wavelengths to higher wavelengths. The ratio of the increasing amount of emitted power to the total power from both sources as each new wavelength increment is added shows the relative significance of the emitted power from the particular type of surface with respect to the total power.

7. Experimental Equipment

Infrared line scan data for this project were taken with a Daedalus Line Scan System. This radiometric system features modular design and tape recording of video data, and it was specifically designed for an airborne platform.

Radiometers and spectrometers measure the intensity of EMR from the ultraviolet wavelength to radio frequencies in given preselected bands. These instruments are most used in the IR and microwave portions of the EMR spectrum. For a more detailed discussion of infrared measuring instruments in general, the reader is referred to Wolfe (1965), Holt (1962), and other texts on infrared technology.

The aircraft in which the Daedalus thermal line scanner was mounted was a Piper Cherokee 6, a low winged, single engine aircraft. The line scan system consisted of three basic units, the scan head, the control console and the tape recorder (see Fig. 10). The scan head fits into a standard 9-inch camera ring mount which is used for aerial photography cameras.

The axe-bladed scan mirror is driven at 3600 RPM by an AC synchronous motor with a bellows shaft and powered by a tuning fork oscillator to insure rotational stability. The scan mirror provides

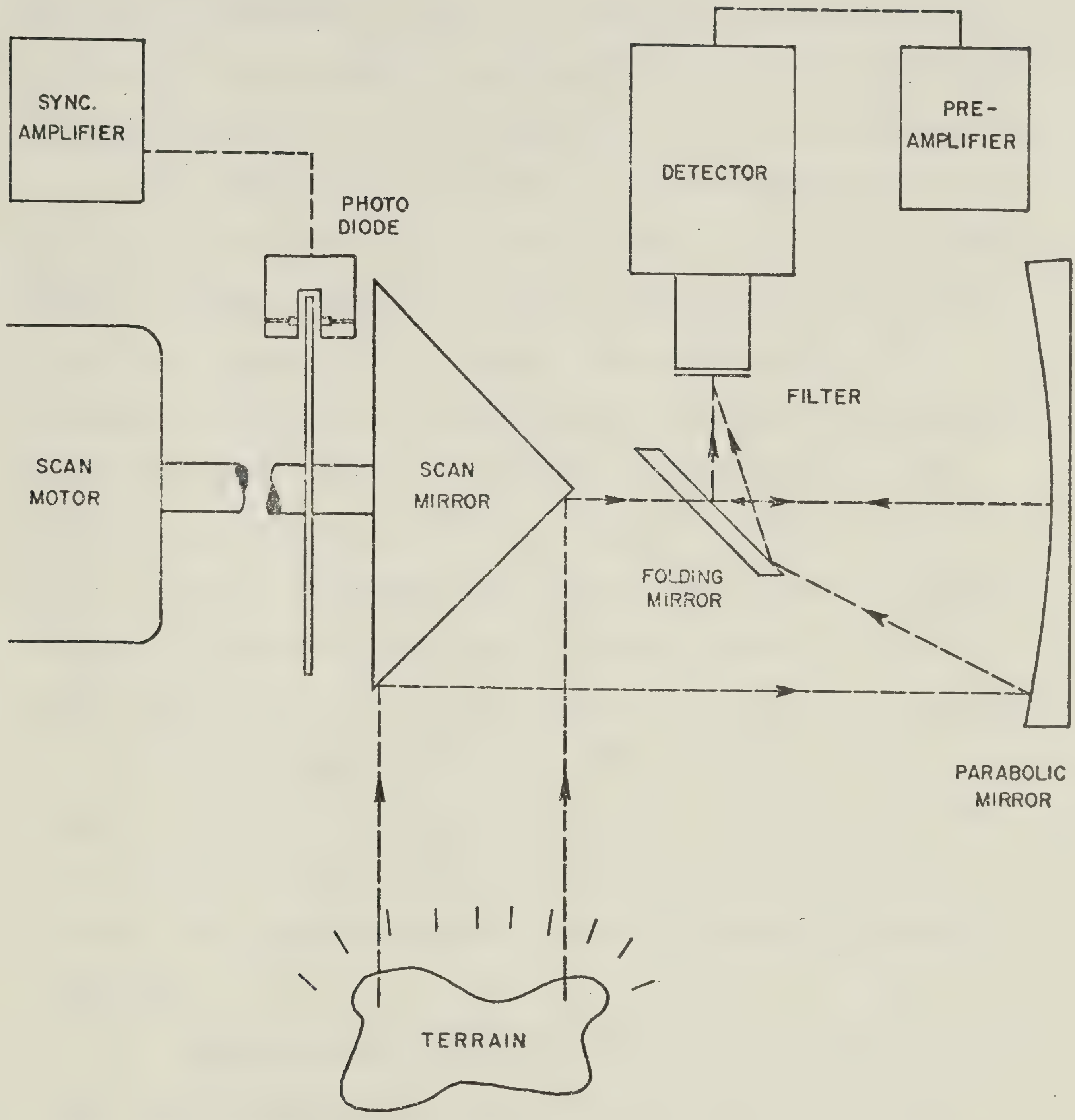


Figure 10. Scanner optical ray diagram. (Daedalus, 1971)

a scan rate of 60 line scans per second. The forward motion of the plane produces a line of scans leading to a line scan image.

The optical path for the radiation received by the scanner aperture is illustrated in Fig. 10. Radiation from the terrain is reflected by the scan mirror onto the parabolic collector and then brought to focus on the detector by means of the folding mirror.

Two detectors were available, a Ge:Cd:Te (Trimetal) for the 8 μm to 14 μm IR window, and an InSb for the 3.5 μm to 5.5 μm window. Since the process of emission in the IR range is almost entirely a function of temperature, the choice of detector is based on the response of the detector to specific surface temperature parameters. The Trimetal detector is more responsive to temperatures of 273°K and below; the InSb detector is more responsive to temperatures of 283°K and above. This means that if detail is required in cold target areas, the Trimetal detector should be used; if imagery is to detect warmer spots in the ambient background, an InSb detector will perform best (American Geological Institute, 1968). See Fig. 11 for a graphic illustration of detector sensitivity. For this project, the InSb detector was used. It was filtered with a 4.5 μm filter to increase the desired response and to lower the amount of reflected radiation.

The EMR passing through the detector generates an electrical signal that is amplified and taped. The panel which controls and monitors the signal consists of an oscilloscope which may be used to monitor the scanner signal or the reproduced signal from the tape recorder, a "sync. mixer" which allows adjustments to the signal to

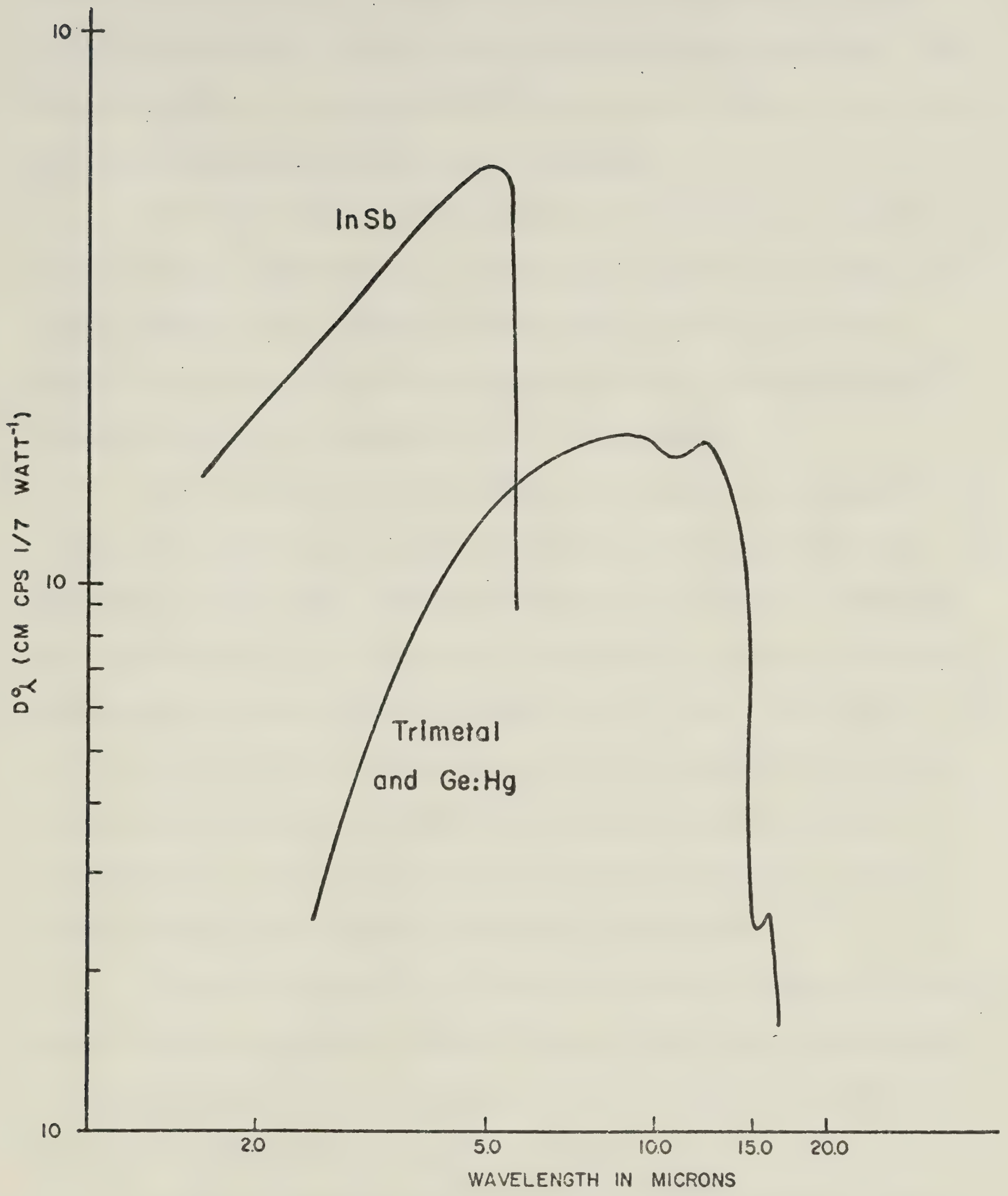


Figure 11. IR detector response. (American Geological Institute, 1968)

obtain optimum contrast in a given set of conditions, and remote control switches for the scan head and tape recorder operation. The adjusted signal is recorded on 1/2-inch magnetic tape on 7-inch reels. The data are stored permanently on the tapes.

To convert the data from tape to film, Daedalus supplies a Field Printer. Essentially, the electrical signals on the tape are played through a low retention phosphorous glow tube. A 70 mm camera is set up to film these signals which will reconstruct the thermal image of the terrain as seen by the scanner.

The end result of this process, the ground to scanner to tape to film process, is a black and white picture of temperature patterns on the ground. The resolution of the scanner at 1000 feet above the ground is 2.5 feet across the ground. That is, the scanner will pick up objects that are larger than 2.5 feet. The field of view at that altitude is 1000 feet across the ground, perpendicular to the line of flight. At 2000 feet above ground the scanner resolution is 5 feet, and the field of view is 2000 feet. Normal flight altitude was 2000 feet above mean ground level.

Since the imagery is of heat rather than of physical objects, colour aerial photography, infrared false colour aerial photography and ground truthing were all done as simultaneously as possible for positive identification of specific objects.

Machair of Calgary supplied the aerial photography. They produced standard 9 x 9 inch, 60 per cent overlapping photographs taken by a Wild RC-8 camera mounted in a Cessna 206 aircraft. The scale of the photos is 1:10,000.

Kodak film was used for both the colour and false colour infrared photos. Aerochrome IR (estar base) film, No. 2443 is a false colour reversal film with a high dimensional stability for forest surveys and camouflage detection. Ektachrome MS Aerographic (estar base) film, No. 2448 is a color reversal film for low to medium altitude aerial mapping and reconnaissance. Both films were used in this project.

CHAPTER III

REMOTE SENSING INTERPRETATION

1. Purpose of Interpretation

The purpose of this experiment was to determine the potential usefulness of colour and false colour infrared photography and thermal infrared line scanning as a means of remotely sensing the earth's natural environment. A site near Calgary, Alberta was selected and was surveyed three times during the summer of 1971, each time using the three mediums of remote sensing under discussion. A limited amount of ground checking was undertaken; this consisted of identifying crops and other features that might present some difficulty when interpreting the photos or the line scan data. Since the potential use of remote sensing is to extend test sites or to locate problem areas, it was felt that if a high degree of familiarity with the test site was developed on the ground, it would influence the actual interpretation of the photos. Therefore, aside from the rather limited ground program, the information gathered is entirely from the sensor imagery. The emphasis of the thesis is on the location of problem sites within the area with the purpose of studying the usefulness of the three remote sensing mediums.

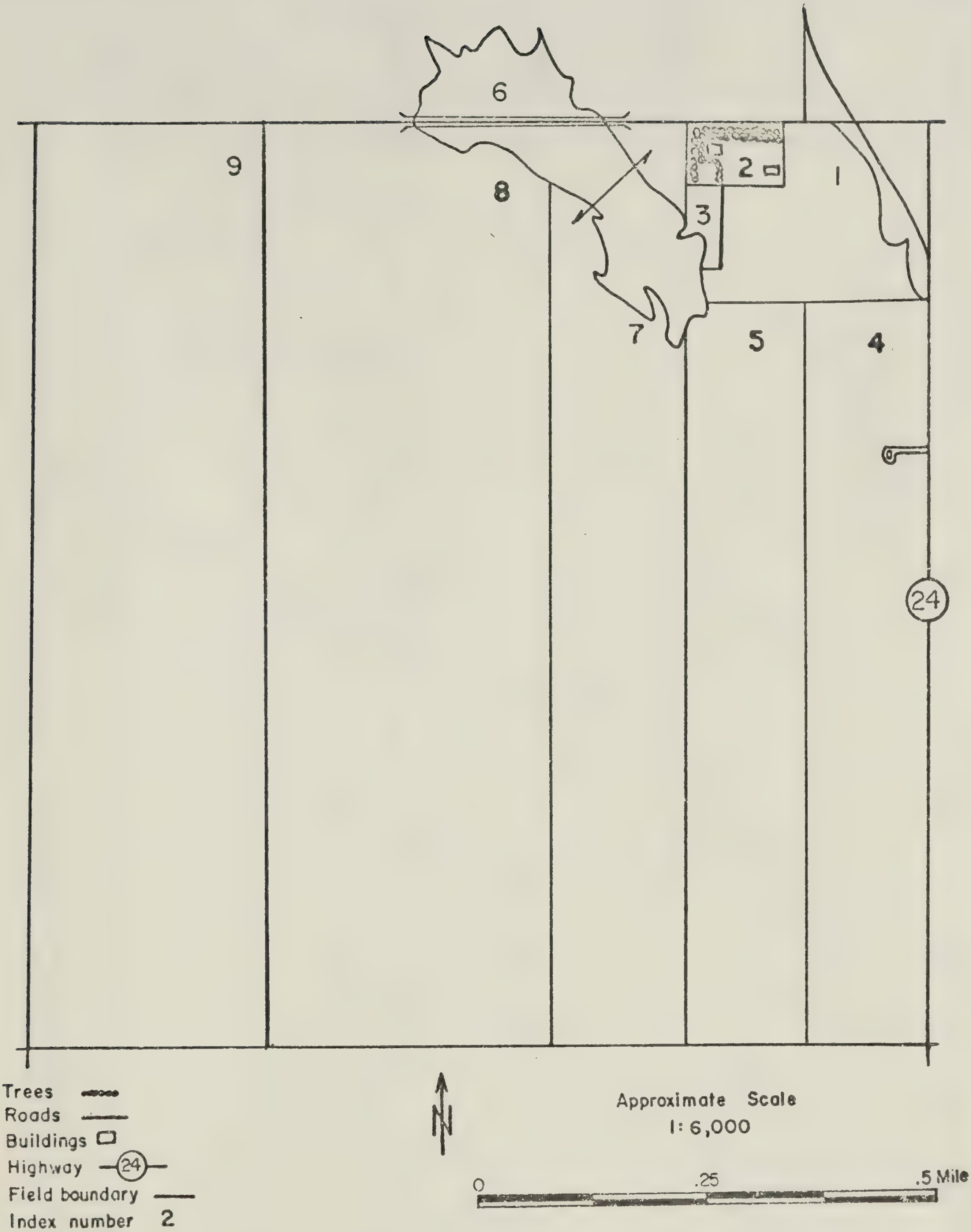
2. Experimental site

In an effort to determine the potential usefulness in an agricultural environment of the three remote sensing mediums under discussion, an area of one square mile, centering on a point 113° 33' 35" W longitude, and 50° 53' 35" N latitude, three miles northeast of Dalemead, Alberta was selected (Fig. 12). It was surveyed three times during the summer of 1971. It was originally intended that coverage in colour, IR false colour aerial photography, and thermal infrared line scanning would be accomplished simultaneously. For various reasons this was not possible. Maximum and minimum temperatures and precipitation are given in Fig. 13 for the summer of 1971 at Calgary, Alberta, the closest weather station available.

TABLE 2

DALEMEAD SURVEY SCHEDULE, 1971

Date	Colour	Infrared False Colour	Thermal IR
June 10			*
June 20		*	
June 28	*		
July 15			*
July 19	*	*	
August 24	*	*	
August 26			*



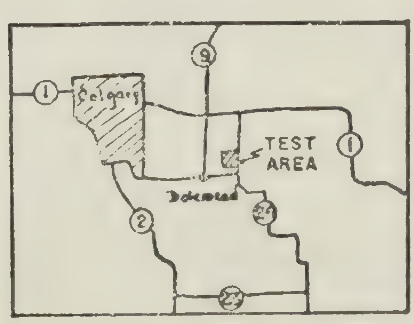
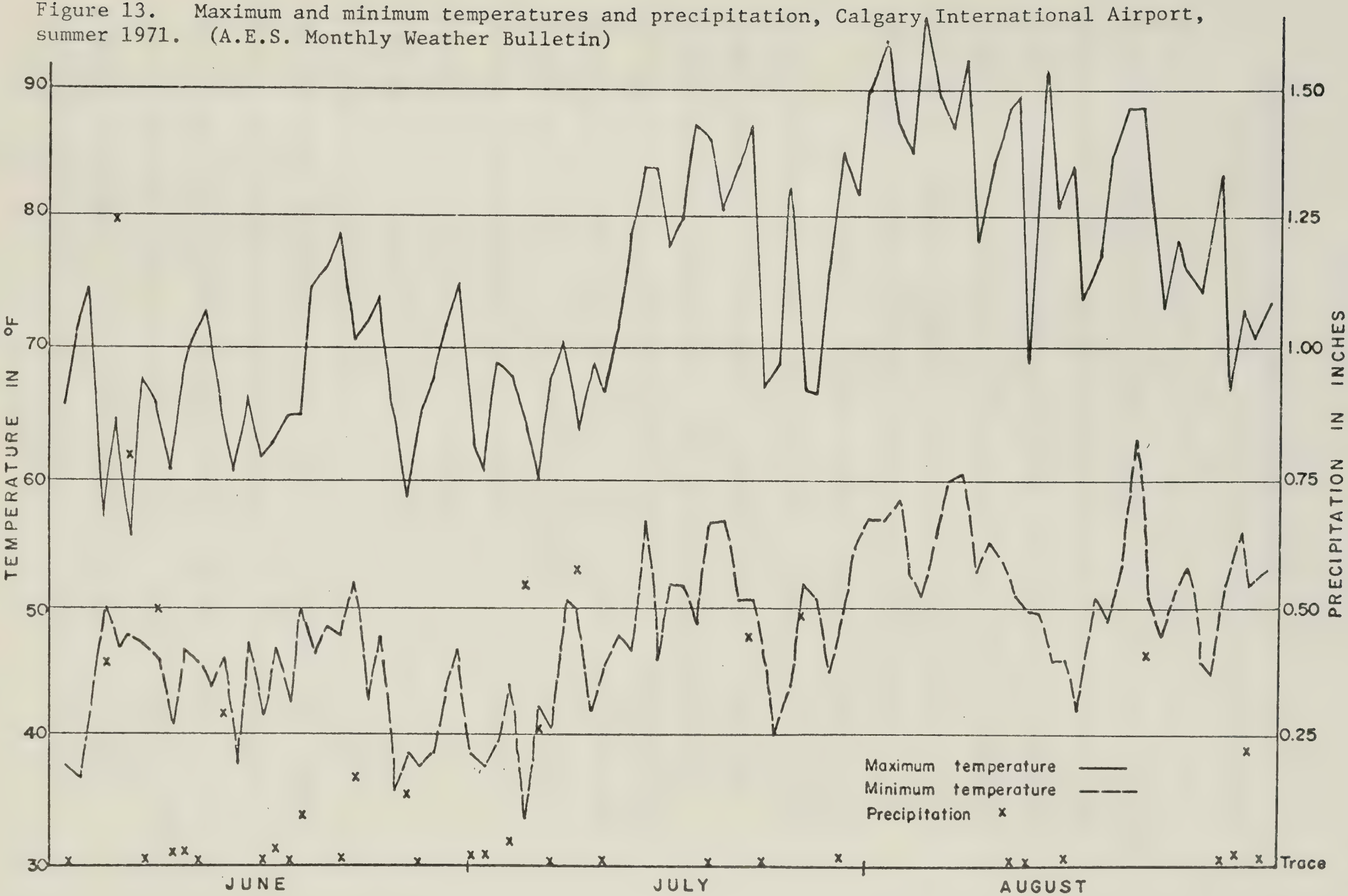


Figure 12. Dalemead study area field index and location.

Figure 13. Maximum and minimum temperatures and precipitation, Calgary International Airport, summer 1971. (A.E.S. Monthly Weather Bulletin)



3. Interpretation of Field Data (Introduction)

Each field in the test area is discussed individually using first the colour film, then the infrared false colour film. This format is followed first for June, then for July, and finally for the August flight. After the initial discussion of a given type of crop, which is identified on the ground, only the unusual or outstanding features of a field are noted. The thermal infrared line scan data will be discussed after the photo interpretation and in the light of the information obtained by the above two photograph mediums.

Figs. 18 and 19 were taken from the July 19 flights. The flight on this day resulted in particularly good photographs due to proper exposure and development. It should be borne in mind when interpreting photographs, that often the photos themselves are of poor quality with questionable colour reproduction. For example, the false colour infrared photographs exposed on June 20 (Fig. 15) were of poor quality due to a very heavy blue shading. On this flight, actively photosynthesizing plants returned a series of purples instead of the bright reds that should have been present. To complicate the interpretation further, it was observed that one field exposed at the beginning of the flight and again at the end of the flight did not give the same return, even though edge effects of the film were removed because the field was in the same position with respect to the center on both photos. The edge effects referred to are the tone changes within each photo as one progresses from the center to the edges; in the center the tone is lighter and colour differentiation is more easily observed than around the edges of

the photo. Thus, a field on two photos may appear very different due solely to its position on the photo with reference to the center point. Aerial photos should be interpreted as a stereo pair whenever possible. While a particular pattern may be evident on a single photograph, observation of a stereo pair will bring out elevation variations that increase the ease of interpretation.

Due to the number of uncontrolled variables in photographic interpretation, experience with a particular environment and photographic medium is the best method of obtaining the most information from the available photographs. Photo interpretation is defined within this thesis as a subjective method of visually obtaining information about a particular environment from aerial photographs. Photogrammetry is defined as the science of obtaining physical measurements of the earth's surface from aerial photographs. Photogrammetry is not dealt with specifically in this thesis.

In reading the following photographic interpretation section, frequent reference should be made to Figs. 14 through 19 in order to build up an appreciation of each type of presentation within the initial framework of the discussion.

The Dalemead test area (Fig. 12) exhibited hummocky, low, rolling hills, and sandy soils formed from glacial deposits. A high water table was indicated by the number of hollows and sloughs containing water. Because of the furrow marks in the bottom of some of the flooded areas, it was assumed that in past years the water table was probably lower. There was a high salinity condition throughout the area which was enhanced by the dry summers and a high

Figure 14.   June vertical air photo of Dalemead test area, colour.

N

Figure 15. June vertical air photo of Dalemead test area, infrared false colour.

Figure 16. July vertical air photo, enlarged, of fields 1, 2, and 3, colour.

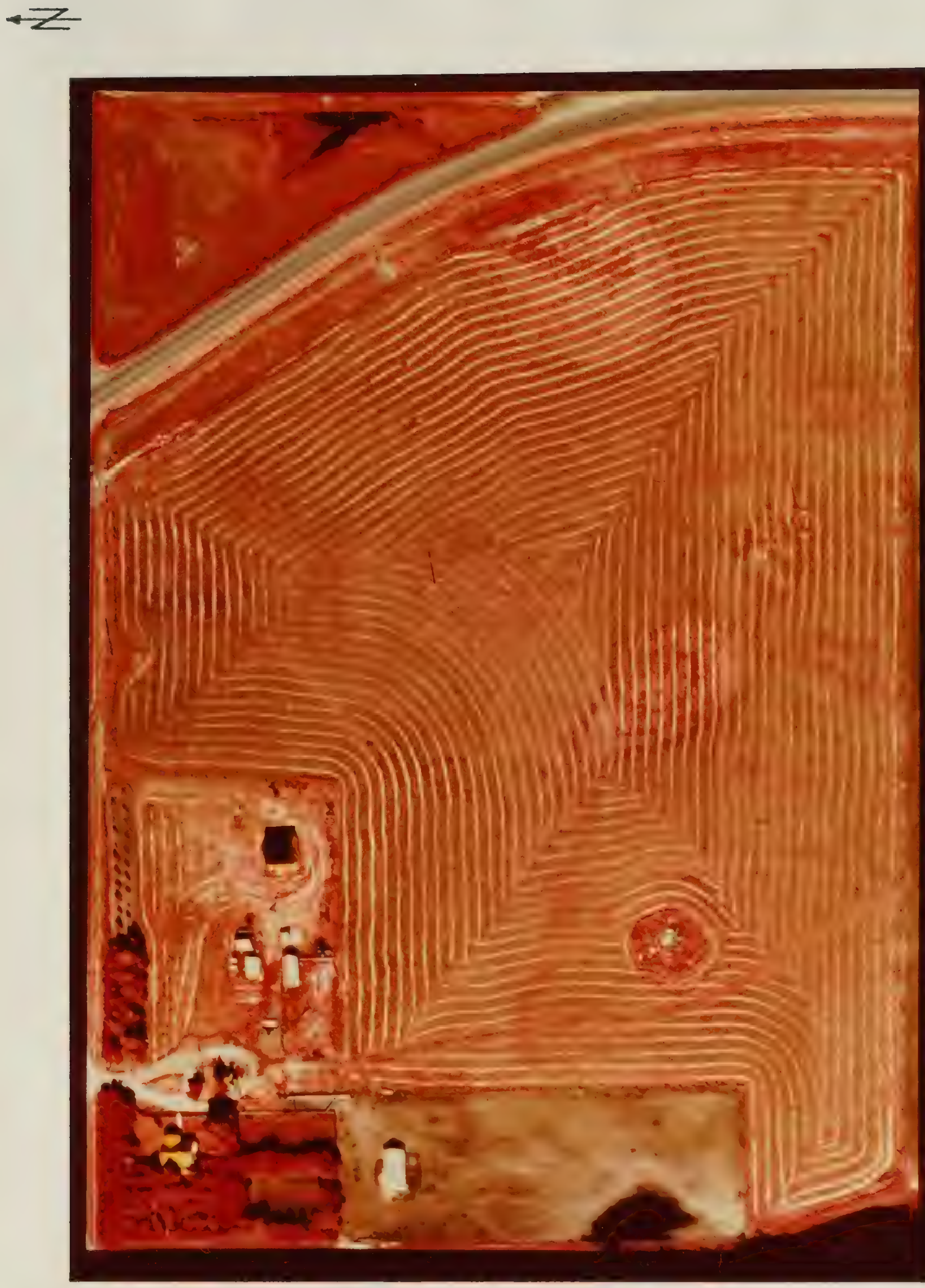


Figure 17. July vertical air photo, enlarged, of fields 1, 2, and 3, infrared false colour.

Figure 18. July vertical air photo of Dalemead test area, colour.

N

Figure 19. July vertical air photo of Dalemead test area, infrared false colour.

water table. Further discussion of the area is presented below on a field by field basis. The majority of the fields were similar in regard to features mentioned above. Therefore, an attempt has been made to limit discussion to each field's unique characteristics.

When interpreting photographs, it must be remembered that the conclusions reached are often very subjective and strongly dependent on the interpreter's previous knowledge of the ecological relationships under study and how these factors contribute to the final photographic presentation. For example, a given tone change observed within a field may correlate strongly with field elevation. This can be seen easily by use of a stereoscope. However, the same change of tone may also reflect a soil moisture variation, a change in soil chemistry, a modification in plant species, or a series of other related changes. A photograph is basically the result of a chemically-treated surface subjected to varying intensities of electromagnetic radiation. It must be remembered that there is a long inferential chain of reasoning leading from intensity of solar radiation to a change in soil moisture. However, a distinct difference can be drawn between the quantities that can be measured on a photo and directly related to the ground, that is, tone changes in the photo related directly to tone changes on the ground and the quantities that can only be inferred subjectively from a tone change on the photo, that is, the tonal response difference of plants can be related to soil moisture, but this may be only one variable affecting plant growth. The distinction between these two classes of observations is attempted in the following section by the identification of each subjective observation when it is made.

4. Field by Field Interpretation

The ground cover on Field #1 was grass (Fig. 12). This was verified by ground information. In June the colour photo (Fig. 14) returned a deep green with a very slight indication of cultivation because of the weak banded pattern. Otherwise, the grass was very even, with a slight change in green tone due to elevation changes. Vegetation was very scarce in the slough bottoms; this was indicated by the brown soil return. Note that the plants appeared to be in rows in the slough bottoms. This indicated that the area had been cultivated in past seasons. A high water table was evidenced by the large water-filled slough immediately to the west of the field. The encircling ring of light green vegetation at midpoint on the slopes around the slough was a series of mosses and other low plants that can tolerate a high soil water content. They also exhibit a light green colour when observed on the ground. The very apparent change in vegetation from slough bottom to average field height would appear to be related to soil moisture differences because the moisture differences in the soil were extreme. This gave further support to the previous interpretation that the area has a glacially deposited, sandy soil with a high water table and therefore, a low water retention. Note the small slough just east of the farm road through the field; the white return around the edges was from rocks that were dumped there. Careful observation of the photo revealed that the material in the center portion was too angular to be rocks; this slough was probably also used as a garbage dump. Ground observation showed that this slough was filled with rocks with a few pieces of discarded metal in the center.

On the infrared (IR) film, (Fig. 15) the most noticeable difference in comparison to the colour film was the prominence of the previously mentioned light green ring around the sloughs; the IR film showed this as a light purple, contrasting to the dark purple of the grass. The slough bottoms were a deep green which indicated a very moist soil condition. The trash and rocks in the slough bottom referred to earlier returned a white that was similar to the return of the gravel road; this was a further indication that the majority of the material in this slough was rock. It should be remembered that the IR film pictured very little that was not also on the colour film. The major difference is related to the ability of the human eye to see more differentiation in the red tone than in a green one. Thus the IR false colour increases the ease of interpretation and allows more to be observed. On IR film water return a black tone, and mud shows up as dark green. Moisture fluctuations within a given field can be easily observed as changes in the green tone.

In July, (Fig. 16) the field was swathed. In the southwest corner the swathing returned a brighter white tone. Observe throughout the field the growth recovery as shown by green clumps on the colour film (Fig. 16) and the red clumps on the IR film (Fig. 17). The slough on the west side at the highway had a north to south strip of white on both the colour and the IR films. This was probably a small surface salt deposit. On IR film, note the deep red tone immediately next to the white strip. Then note the lightening of the red tone as one moves toward the highway. This deepening of red tones immediately

next to a white return strongly suggests salt poisoning. IR film, one layer of which is sensitive in the near infrared wavelengths, emphasizes the infrared reflectance of healthy green vegetation; this appears as bright red or pink on the photographs. Plants affected by salinity appear as darker shades of red, and when seriously affected, very dark. White areas on the IR photo are accumulations on salt or bare soil surface areas, (National Academy of Sciences, 1970). The sloughs in this field were worked as is evidenced by the continuous pattern of swaths through them. The vegetation recovery in the slough bottoms covered the soil that was bare in the June flights. This points to a lowering of the water table as the summer progressed.

In August vegetation recovery was more apparent than during the previous two months. The water table had dropped further. Flying the same area more than once in a short time interval led to a decrease of new information with each subsequent flight. This observation would not hold true for a specialized study where something such as water table fluctuations are of interest.

Note that Figs. 15 and 17 were both taken with the same camera and similar film. However, Fig. 17 was properly exposed and this made the interpretation much easier and more informative.

Field #2 contains a farmhouse and the surrounding yard. On the colour photo (Fig. 14), the house roof was red while the barn roof was black. Note that the grass immediately around the house was cut evenly as evidenced by the smooth green return. Compare this to the patchy green of the farm yard. The amount of trampled grass gave an indication of the intensity and destination of traffic.

The amount of machinery scattered about was rather small but appeared to be neatly placed. This was in indication that the farm was run efficiently. Immediately south of the house were two plots of land that appeared to be used as home gardens. The small size indicated that they would not be practical as a commercial venture. The plot surrounded by trees appeared to have nothing growing in it; the other had approximately eight rows of a broad-leafed, low plant, possibly potatoes. The trees immediately west of the house were ground identified as caragana. The single row north of the house was also identified as caragana. The row next to the road was poplar and the smaller trees at the northeast edge of the yard were small spruce. Differences in crown size and height allow one to differentiate among them on the photos.

The IR film (Fig. 15), showed a greenish yellow farm roof and a black barn. A very even tone of purple showed in the house yard and this may be compared with the patchy purple in the barnyard. Compare the patchiness of the farmyard on the colour photo (Fig. 14) to that on the IR photo (Fig. 15) and at the same time, note that the vehicles in the yard have changed position. (The photos were taken 90 minutes apart.) This indicated that the people were actively working in the area. The IR photo, (Fig. 15) is very poor and the potatoes that were visible easily as eight rows in the east garden are almost invisible. The trees that could be differentiated by species in the colour photo are easier to differentiate on the IR photo because there was a strong tone difference with the caragana being a much lighter purple than the poplar, and the spruce was a bluer shade of purple.

In July (Fig. 16), note that the farm yard had been swathed and that the house yard was turning brown. The potatoes were a little larger in July, and in the other plot surrounded by trees, several north-south rows were visible. On the IR film (Fig. 17) note that the house yard was a dull tone of red, indicating a moderate vigor. The swathed material, which was dead straw, returned a small amount of infrared reflectance and thus is white. Both gardens were doing well and showed a bright red return as did the trees and portions of the barnyard not yet swathed. Note the absence of any buildings that appeared to be suited for animal shelter or feed storage.

In August, the cut hay had been gathered, but no other new information was obtained from the photos.

Field #3 was a pig sty. This was apparent on the ground as well as from the air photos. On the colour film (Fig. 14) note the complete lack of vegetation. This soil appeared to be moist because of the dark tone, but this became lighter as one approached the slough in the southwest corner of the field, possibly due to a surface deposit of alkali . The animals that were in the field could be seen as white dots near the water's edge. It appeared that they had spent considerable time in the water as there was a large amount of suspended sediment in the water as indicated by the brown return in this part of the slough. The single shed in the field was probably used as a combination shelter and feed storage. In the northwest corner there were several bales of hay next to the fence. Note that they were on the outside of the fence. On the IR film (Fig. 15), the field was completely free of vegetation, shown by

the lack of a purple return, and was very damp, shown by the dark green colour. Note that the lighter ring next to the slough on the colour photo was also visible on the IR photo. This indicated that there might be some salt showing up as a surface crust. Also note the general lack of detail in the water on the IR film. The hay in the north-west corner was a bright white because of the low IR reflectance of straw.

In the July photo (Fig. 16), note the shrinkage of the area in the southwest corner that was water-covered. Also note the increased ease of seeing the suspended sediment in the water. The white ring around this became more prominent and the field in general appeared to have dried out. On the IR film (Fig. 17) the entire area appeared to be damp, but the white ring around the water's edge was dark, indicating a high moisture content. On this photo (Fig. 17) the suspended sediment gave a very slight green return to the water.

In August the field appeared dry and the water had retreated completely from the field. The IR film indicated that the field was moderately moist with a pronounced alkali patch around the edge of the slough. The higher portions of the field had dried out completely.

Field #4 (Fig. 14) was in summer fallow. The amount of straw left on the surface as trash was high and therefore the return of this field was quite light. The building was an Alberta Government Telephones microwave relay station. The shadow of a structure can often be used to give additional details that are not visible from a vertical photo. An increase of soil moisture in the low spots returned a darker brown in these regions. Several of the smaller sloughs were ploughed but their dark brown return indicated that

they had no surface trash. On the IR film (Fig. 15) the surface trash returned a bright white response characteristic of dead vegetation. Soil moisture was evident as green shades; a dark green return in the lower portions of the field indicated a high moisture content. In the sloughs where the trash cover was low the green return was very dark, indicating that throughout the rest of the field much of the green return due to the moist soil was overridden by the dry straw overlying the soil.

In July (Fig. 18), the farmer cultivated through all of the sloughs which may indicate an overall decrease in the water table level. Note that the northern portion of the field had not been ploughed and that it was a lighter tone of brown than the remainder of the field. There was no vegetation present in the sloughs at the south edge of the field and the ploughing not only overturned the earth but caused a striped pattern to emerge; this could be related to small changes in height induced by the plow which appeared to cause a related change in soil moisture and also to the horizontal displacement of trash by the plow. On the IR film (Fig. 19) the soil moisture was indicated by the dark green colour; note the deepening of the green in the southern portion that had recently been plowed. The dark green patches became irregular about the edges. Note that were was some recovery of the vegetation in the sloughs as evidenced by the red response that was barely visible.

In August the field was unchanged except for the decrease in surface trash due to continued working, and a lowered water table created drier conditions.

Field #5 (Fig. 14) was in summer fallow. The only major difference between this field and Field #4 was that this field had less surface trash. This made the observation of soil moisture much easier. On a stereoscope the darker brown areas were all in the lower portions of the field. There were four sloughs that were too wet to be cultivated. On the IR film (Fig. 15) the same things were noticed but again the straw gave a high infrared return yielding a white response on the film and the damp soil returned a green tone.

In July (Fig. 18), Fields #4 and 5 were worked as one. Note that Field #4 appeared as a darker brown. This should not be mistaken as an increase in soil moisture but interpreted rather as a decrease in surface trash. Two of the sloughs that were being worked were beginning to show recovery of vegetation as indicated by the light green speckled pattern within the sloughs. The lighter portion of the field found in the northern half was an indication of how a field dried out leaving a surface crust. Cultivation turns up soil by breaking up the light brown crust and turning up the moist soil beneath. Note the recovery of vegetation as indicated by the red spots found within the recently ploughed slough bottoms.

In August the field was unchanged except for a further decrease in surface trash and a lowered water table.

Field #6 (Fig. 14) was a large slough. Note that the center portion was shallow as indicated by the growth of vegetation with a moat of deeper water around it. Inspection of the raised area near the road indicated a furrow pattern as evidenced by the straight lines of vegetation running northeast to southwest. Once the water's surface had become matted with vegetation in the southern portion of

the center section the striping became much less obvious. The water's edge was easy to see as long as there was little vegetation. When vegetation began to grow into the water, the edge became obscured as in the southern portion of the center section. Thus it could be stated that in the past there must have been drier periods during which the water table was low enough to allow ploughing of this large slough. The June IR film (Fig. 15) showed all of the above-mentioned features; it also showed only the ploughed portion of the center section above water. The southern part of the center portion where no strips were visible was very faint due to the predominance of the black water return.

In July (Fig. 18) the water level had dropped within the slough. The center portion above water had expanded especially in the southern portion, and the green return was much stronger, indicating that the plants were above water. The topography within the submerged section was visible on the colour film which had much better water penetration than did the IR film. The July coverage was largely a repetition of the June coverage. On the IR film (Fig. 19) compare the bright red of the ploughed furrows in the center section to the lighter reds in the lower areas. It appeared that the vegetation around the raised center portion in the drowned soil was not doing as well as that growing on the slightly higher ground. The same effect was also visible in the ring around the outside of the slough.

In August there was a further decrease in the water level.

Field #7 was planted in rapeseed. In June (Fig. 14) the field had a soft, pastel green tint on the colour photos. The

cultivation patterns were evident as distinct rows within the green return. All of the tractor turns were evidenced by increased crop growth in June. This was a result of double seeding and double cultivation due to the farmer going over the area where he turned around in order to pick up the partially-missed areas. A single crop is, in general, of uniform height barring soil differences. On the IR film (Fig. 15) the field's moisture variations were apparent as green undertones in the field's predominantly purple return. This resulted in a darker purple return in the low spots. The larger slough found within this field had surface water. This was evidenced by a very dark center. The dark center was surrounded by a ring of light purple as were the sloughs in Field #1 on the June flights.

In July (Fig. 18) this field had a bright yellow return on the colour film. This indicated that the rapeseed had blossomed. Note the green patches which may be weeds in the yellow rapeseed return. The slough within this field had dried up. On IR film (Fig. 19) the field had turned a bright pink. Note the scattered red return which may be weeds. The cultivation patterns were still visible but were more difficult to see. Maturity of the crop may be evidenced by a change in the pink tone and perhaps a small strip of red indicating that some mature plants have lost their flowers and started to head out, which would again show the green leaves on the colour film and a red tone on the false colour IR film.

In August the field was swathed. In both photos it was evident that the area had dried out considerably due to the fact that a tractor was used in sloughs that were water filled in June.

Field #8 was planted in barley. In June on the colour photos (Fig. 14), the cultivation patterns were plainly visible as parallel strips of light green where vegetation was beginning to appear. At this time there was still a lot of bare soil, visible as a light brown return underlying the green. The tractor marks in the field stood out as a deeper green than the surrounding field. The larger sloughs contained water in central areas as evidenced by the dark brownish return. As one goes outward from the center, note a grayish ring from areas where the vegetation was growing in the water; then a light green ring of low plants such as mosses can be distinguished. There was a ring of brown around most of the sloughs where the farmer had cultivated but not planted. The west quarter of the field appeared to have been cultivated the previous year as a separate field. This was indicated by a distinct underlying cultivation pattern and also by the amount of surface trash which in several of the north-south rows was so heavy that the barley was not visible through the gray strips. The southeast corner of the field was a low area that supported very little vegetation growth as indicated by the light brown return of the soil. On the IR film (Fig. 15), this portion of the field gave a dark green return which indicated that this region was very damp. The large amount of trash in the western quarter of the field gave a bright white return due to the high infrared reflectance of straw. The changes of vegetation colour discussed above concerning the appearance of the rings around a slough on the colour film were also visible on the IR film but they were visible as a series of purples rather than a series of greens.

In July (Fig. 18) the barley had a deep green return. Note the fine strips in the crop that were due to the initial planting pattern. At the corners note where the tractor turned sharply and missed sections, the corners were reploughed and seeded. These areas of better growth were still evident as a different green tone and also as a strip cutting across the general planting pattern. The rows of trash were still in evidence along the western edge as an area where little plant growth was evident. The entire western edge was a slightly lighter tone of green indicating that the growth was not as good as in the rest of the field. Over the entire field the variation of crop growth was visible as patchiness in the green return. With the use of a stereoscope it can be easily seen that this difference in growth was dependent upon height and can perhaps be related to soil moisture. The low portion in the southeast corner showed a definite drainage pattern as evidenced by the beginning of an erosion channel. The deeper green strip running from north to south in the eastern part is an unexplained anomaly. Compare the IR photo (Fig. 19) closely to the colour photo (Fig. 18) and note that each feature mentioned as being on the colour film is visible on the IR film. Especially note that the large slough in the north half of the field clearly indicated a moist soil condition as seen by the green return on the IR film, while a darker brown return found on the colour film in the same place was difficult to interpret as to amount of soil moisture. Ground experience concerning soil moisture and how it is reflected by the film response is an invaluable aid to the photo interpreter in an agricultural situation.

In August the barley had matured to a light brown and weed infestation showed up as green patches scattered throughout the field on the colour film. On the IR film the return of the barley was so high that only a few patches of red, indicating weeds could be observed.

Field #9 (Fig. 14) was in summer fallow. There was only one slough of any size and in June this slough had water in it. The slough itself had a light green return characteristic of low, moisture-loving plants such as mosses. The field was well maintained and no evidence of plant growth was visible. The most prominent feature of this field was the large amount of surface trash on the eastern edge. This indicated that perhaps the western side of Field #6 and the eastern edge of this field were recently cultivated as a single field. On the IR film (Fig. 15) the amount of water in the slough appeared to be about twice the amount that was visible on the colour film. The surface trash in the eastern portion of the field was visible as an increased white return.

In July (Fig. 18) this field showed no change from June except that the slough had dried up, leaving two patches of bare soil where the water existed previously. The larger amount of surface trash was still visible on the eastern portion. The IR film (Fig. 19) had one outstanding feature that was not visible on the colour film. In this field the IR film showed red spots where there was some vegetation patches; these patches were not visible on the colour film. Soil moisture in the field was very prominent in the western portion. In a stereo pair the depth of green is directly related to the relative height of the soil in the field. The darker the green the lower down the slope and the moister the soil.

There were no visible changes in the August photos.

5. Photographic Conclusions

In evaluating the usefulness of these two types of photographic mediums, it was observed that in general each contained the same amount of detail. However, the information was in general more easily discernible on the false colour IR film because the red colours of this film were easier to distinguish than the green colours of the colour film. Thus, an interpreter will overlook less using the false colour IR film.

Colour film has much greater shadow penetration and is easier to expose correctly in use. In general mapping work where photogrammetric measurements may require shadow penetration, colour film will be the superior of the two mediums. In forestry, for example, colour film would allow an easier estimation of tree heights while false colour IR film would allow an easier estimation of tree species.

False colour infrared film, because of its ability to differentiate a water boundary, is very useful for hydrologic surveys involving runoff networks, water boundaries and soil moisture. The detection of plant growth, vigor and certain diseases is facilitated by the use of this film. Also as was pointed out earlier in this study, soil salinity is easily observed on the IR film. However, colour film allows a certain degree of penetration into the water if bottom topography is of interest.

The type of film should be chosen on the basis of the following considerations: type of information desired, the lighting conditions available, and the skill of the interpreter. Air photo

coverage of an area is useful in extending point information such as surface salinity or soil types. It is also helpful when a large area is to be covered because it essentially presents a synoptic view of the earth's surface at a given point in time. When looking for trouble spots or points of potential interest for a future study, air photo techniques can be very useful. Air photo coverage of a previously unstudied area allows the selection of test sites that are not too large to be covered on the ground due to lack of time, money or manpower. This last aspect is the one under which this thesis is undertaken.

6. Thermal Infrared Line Scan Data (Dalemead)

In an effort to analyze the thermal infrared data that were taken at Dalemead, several methods were attempted. Initially a gray scale arbitrarily numbered from one to fourteen was selected. Each field was then assigned a number by visually matching the average field return to the gray scale. It was found impossible to judge accurately what number to assign to any field with this scale. Statistically, no effort was made to see if an arbitrary number selected by visual inspection only was as accurate as when applying a gray scale. It was felt that the degree of subjectivity was the same whether using the gray scale or not. The extreme ranges encountered across small horizontal distances complicated the selection of a representative value for the field. Thus of necessity the discussion would have to be centered upon individual objects within each field. This was felt to be too time consuming to undertake in light of the small return expected.

It can be seen that the majority of the interpretation difficulties were directly related to the method of final presentation of the line scan data on film. The most obvious of these difficulties was the lack of any level of reference which remained constant between or within runs. As a result, water which had the least daily thermal change (see Fig. 6) became the reference level. At dawn (Fig. 20) note that the large slough in the upper right was white indicating that it was warmer than the surrounding areas. At noon (Fig. 21) the same slough was black indicating that it was cooler than the surrounding areas. In simple terms, this moderate daily temperature change within water takes place because water has a greater thermal capacity than most other materials.

A consistent gray scale is difficult to obtain in presenting the final output on film. The darkroom introduces a host of variables over which the interpreter often has little or no control. Such things as too much contrast on the negatives giving only black and white, a change of gray tone due to uneven developing, and often a slow turn around from time of flight to film delivery which makes field checking of interpretation difficult. The majority of these difficulties can be overcome by using a computer to present the thermal data. This method is explored in the next chapter and was not attempted at Dalemead because of a change of line scanners during the season and because of the lack of verification observations at the surface.

Figs. 20 and 21 are respectively the dawn and noon flights over the test area near Dalemead on June 10, 1971. The area covered

Figure 20. June thermal IR line scanning, dawn, Dalemead test area.

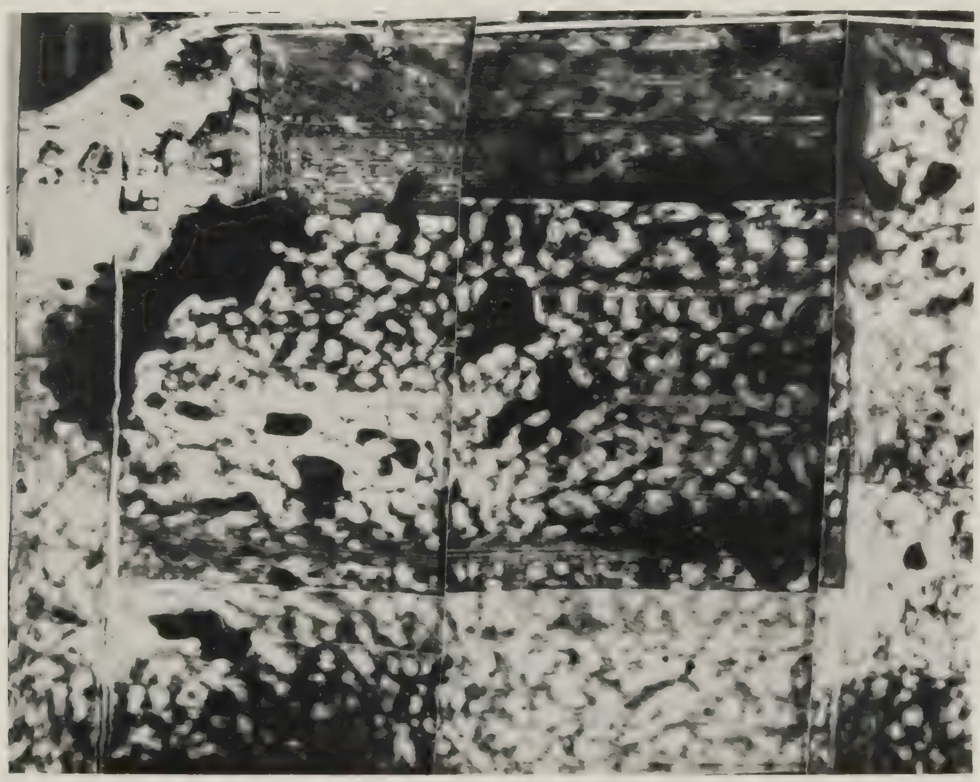


Figure 21. June thermal IR line scanning, noon, Dalemead test area.

is approximately the same area as that discussed in the previous section of this chapter (Fig. 12). On the dawn flight (Fig. 20) the temperatures were rather uniform. The sloughs that contained water were a bright white and the variation in soil moisture was only in evidence as a light mottling effect in the fields. Note that the trees surrounding the farm house were quite cool, as was the Alberta Government Telephones microwave tower on the eastern edge of Field #4 (Fig. 12). The tractor marks where the farmer turned while ploughing the field showed up warmer than the surrounding area because of the slightly more compacted soil allowing more heat transfer from below. Note in the northern part of Field #5 where the earth had been trampled by the tractor that the ground was slightly cooler due to the increase in soil moisture in these areas. The noon flight (Fig. 21) showed a complete reversal. The water-filled sloughs were completely black indicating that they were the coolest areas. The ground surface itself was often very warm giving a white return. However, the sudden changes of soil moisture contributed to the sudden temperature changes that caused the extreme mottling effect found in most areas. Notable exceptions to this were Fields #4 and 5 which were in summer fallow with a straw cover. The moisture was more evenly distributed beneath the straw and these fields did not exhibit the dramatic temperature changes evident in the other fields.

The other flights undertaken in July and August returned almost identical results except that as the crops became higher within the fields, the crop had a cooling effect that was very noticeable on the noon flight; there was almost no difference on the dawn runs.

Notice that the photos of the thermal data appear fuzzy; this is a result of the military-imposed restrictions on the instantaneous field of view of the scanner. During the summer of 1971 these were set at 2.5 milliradians. Thus the scanner tends to smooth sudden changes of temperature that do not extend over the instantaneous field of view which for Dalemead was 167 cm^2 because the data was taken at 670 meters above the ground.

As a result of the examination of the three flights of thermal infrared imagery, it is felt that the same information could be obtained from photo coverage as an aside to the other information. It is not implied that the thermal infrared line scan process has no value, but rather that its potential application to such fields as micrometeorology is great when a method of presentation is developed that will allow the data to be calibrated and presented in a manner such that a selected area can be accurately analyzed.

CHAPTER IV

COMPUTER PRESENTATION OF THERMAL LINE SCAN DATA

1. Computer Programs

In an attempt to overcome the shortcomings of the thermal infrared imagery presented on film, as discussed in the previous chapter, a computer-based presentation system was developed. The data were originally recorded on analog magnetic instrumentation tape using a Lockheed 417WB tape deck. To make the data compatible with the University of Alberta's IBM 360-67 computer, the analog data were digitized. Digitizing was done on the Institute of Earth and Planetary Physics' Nova 1200 computer using the following format: each line scan signal was divided into 512 parts or windows, starting at the left temperature body and ending just beyond the right temperature body, which resulted in approximately 207 windows on the ground portion of the scan signal. The voltage level within each window was averaged and a value assigned. This value was then written onto 9 track tape which stored each line scan as a separate block of data.

An area near Hinton, Alberta was chosen as the area to test the computer output. This area was selected because the Canadian Forestry Service is presently conducting an on-going series of experiments with forest regeneration and they have expressed interest in the possible future use of the computer presentation of thermal remote sensing data. The area lies approximately 43 miles northeast

of Jasper and three miles west of Hinton and is a partially clear-cut area in which some strips of forest were completely removed, while other portions were left standing. The test area is within the lease of the Northwest Pulp and Paper Company. Thermal imagery was flown at 1000 meters above ground level at 6:45 a.m. on October 7, 1971 using the InSb sensor (see Fig. 22).

Four programs were developed to allow the presentation of the digitized data. The first (PRINTOBJ) divides the digitized data into 16 levels using ±2.5 volts as the upper and lower limits. The zero voltage portions of the signal between each temperature body is dropped and the ground scan data with a temperature body on each side is printed. Each level is portrayed as a hexidecimal symbol and is printed by a standard IBM line printer at 6 lines to the inch. The second program (SHADEOBJ) is identical to PRINTOBJ except that the line printer output is overstruck eight times to give a 16 level gray scale in place of the hexidecimal symbols (see Fig. 23). Both programs are limited by the rigid symbol size of the line printer; this produces a linear distortion of approximately a factor of 10 in the flight path direction. The third program (LEVCON) performs a similar function except that the 16-interval output is placed on magnetic tape as integer half words to the base ten. This is then used as input into WXMAP, the fourth program. WXMAP is a plotting routine (see Fig. 24). The data from LEVCON is loaded into WXMAP where it is smoothed and a bias is added to each level that retains a zero decimal. Smoothing is undertaken in an effort to simplify the data field by reducing the number of very small closed contours; this reduces the amount of computation time required for a plot. The bias is added because

Figure 22. Thermal IR line scanning, October 7, 1971, 6:45 a.m., near Hinton. Outlined areas A and B refer to the areas covered by Fig. 23 and Fig. 24 respectively. X indicates the hygrothermograph site.

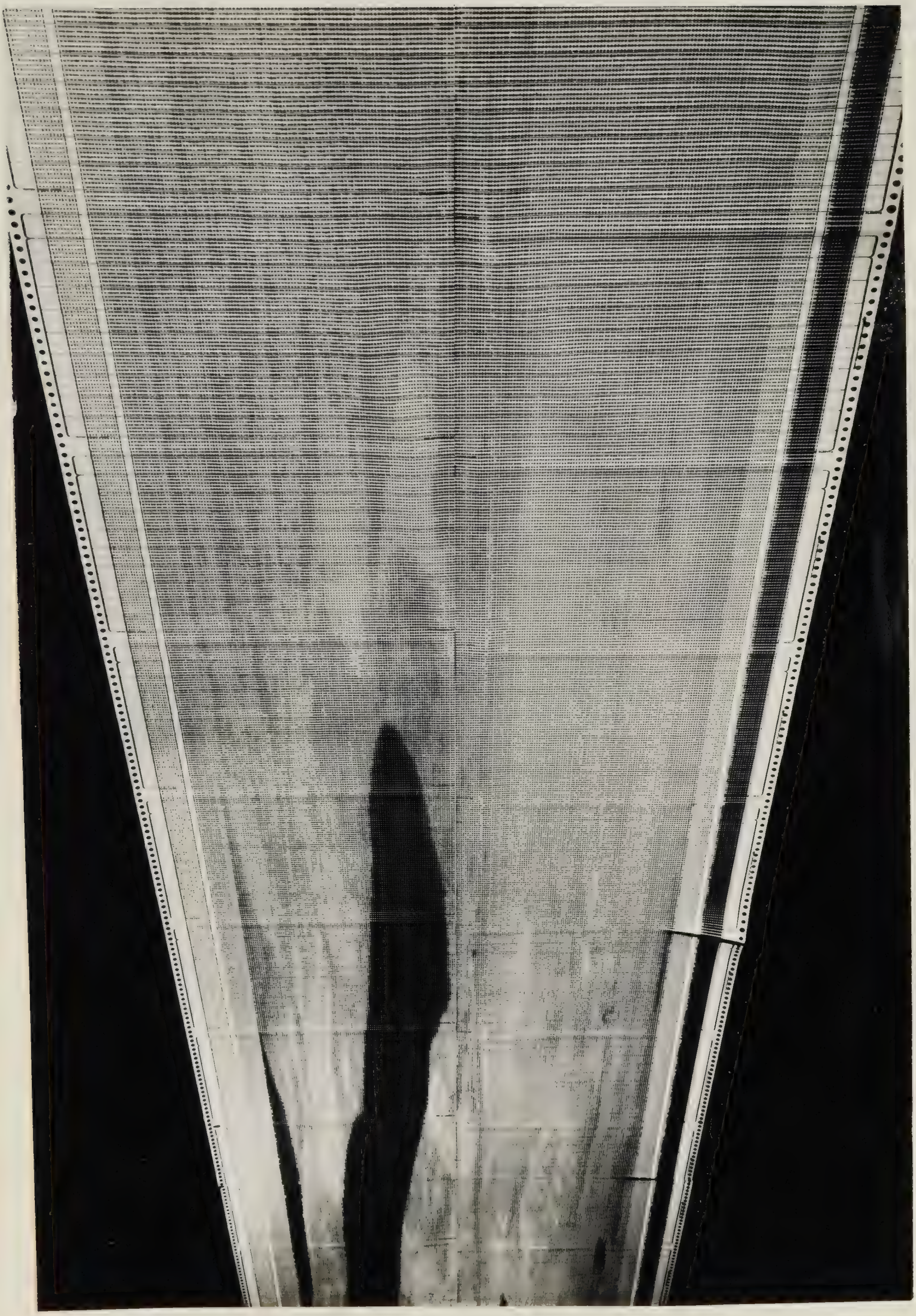


Figure 23. Thermal IR line scan computer output of SHADEOBJ for Hinton, October 7, 1971, 6:45 a.m.

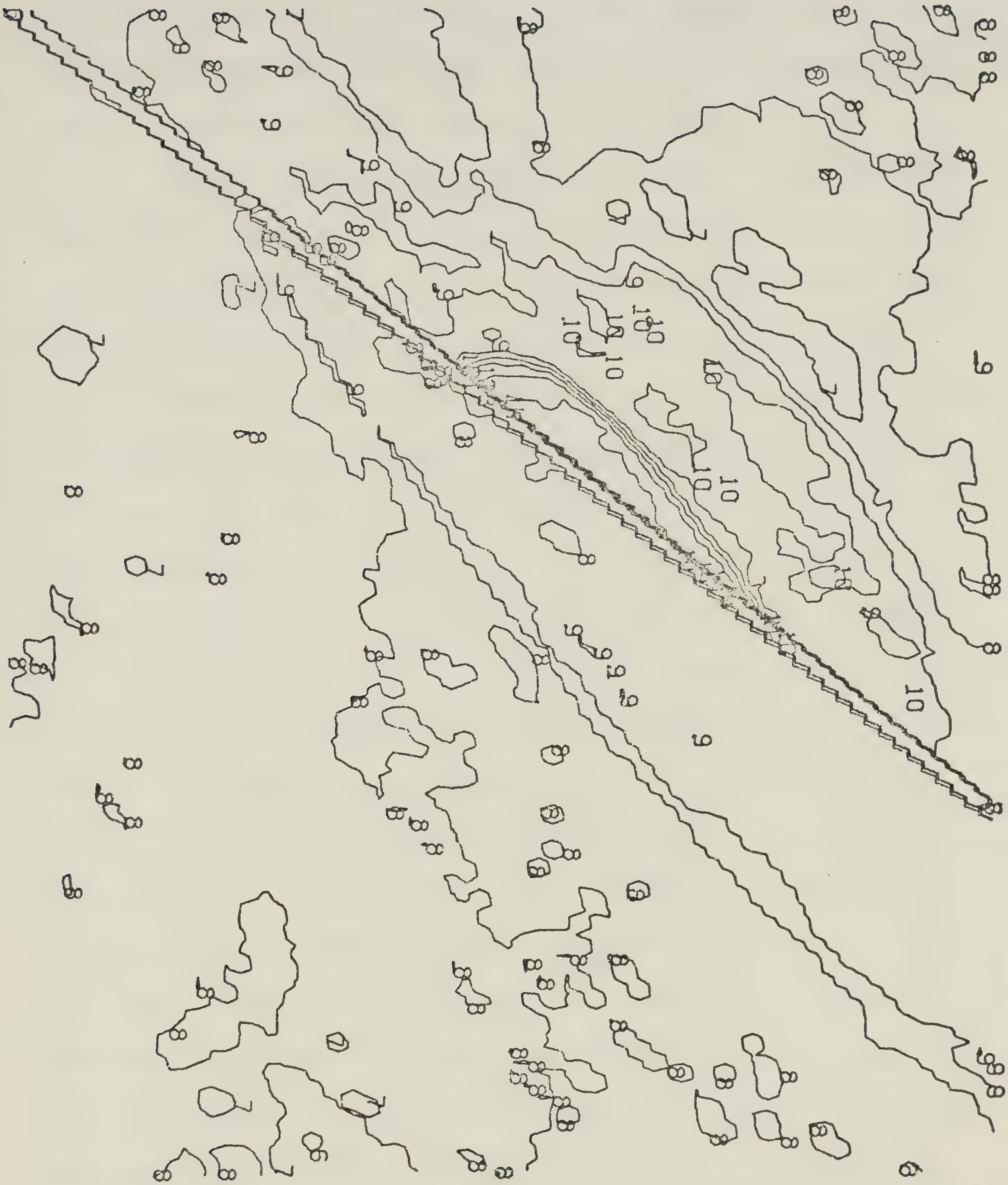


Figure 24. Thermal IR line scan computer output of WXMAP for Hinton, October 7, 1971, 6:45 a.m.

only an integer value contour can be plotted. Should WXMAP find a field of values exactly the same as the contour being plotted, each value is joined to all the others of the same value.

Note in Fig. 24 that a road cuts through the plot from the upper left to the right. Perhaps the most noticeable feature of the road on the contour map is the saw-tooth pattern. Close inspection of all the contour lines reveals a similar pattern. This is the result of WXMAP plotting between data points by linear interpretation. Smoothing of the contour lines is available within WXMAP but was not used due to the high cost of this program. Careful inspection of Fig. 24 expecially in the vicinity of the high values found along the road reveals the fine decisions that WXMAP is capable of making.

Considering LEVCON as a subroutine of WXMAP, three different output formats are possible. PRINTOBJ and SHADEOBJ outputs are very similar. They both require approximately the same amount of computation time, but SHADEOBJ requires eight times the temporary storage to hold the right half of the scan while the left half is being printed, so SHADEOBJ is limited by temporary storage to 1/8 the number of scans per run as PRINTOBJ. Using the University of Alberta's MTS system, it is felt that PRINTOBJ is the more useful of the two programs. It allows one to determine the exact range of the data and to see the range in values across a very small area. It also presents the largest number of scan lines per run of any of the programs.

The biggest drawback of the computer presentation is location identification. In order to do this it is best to resort to the film (Fig. 22), the original method of presentation, find a prominent

feature, estimate the number of scans from the start, then pinpoint this region with PRINTOBJ. SHADEOBJ could be used as well but tends to be more expensive. A final presentation of apparent temperature levels can then be produced with WXMAP.

2. Use of Computer Output

In order to make effective use of the output, a graph is drawn (Fig. 25) so that each level value can be associated with an apparent temperature. The relationship between temperature body response is exponential from 0°K; however, across the very narrow range found within this study a linear relationship may be assumed. In order to determine the temperature range of each level on the graph, the temperature body values are placed along the sides with the temperature range found on the scanner log sheet along the bottom. The two temperature body values are joined with a straight line and where the temperature value on the bottom of the graph intersects this line, one finds the level that represents it on the computer output. In this case level seven represents approximately -0.5°C.

SHADEOBJ covers on the scanner film strip (Fig. 20) the approximate area from the bottom of the strip to the first road cutting diagonally across the flight path, just below the two dark parallel noise lines on the film. By using PRINTOBJ the lake surface has a hexidecimal value of 'E', the road has a value of '9', and a hygrothermograph located approximately where the X is on the scanner film has a value of '7' or '8', depending on the exact location. By

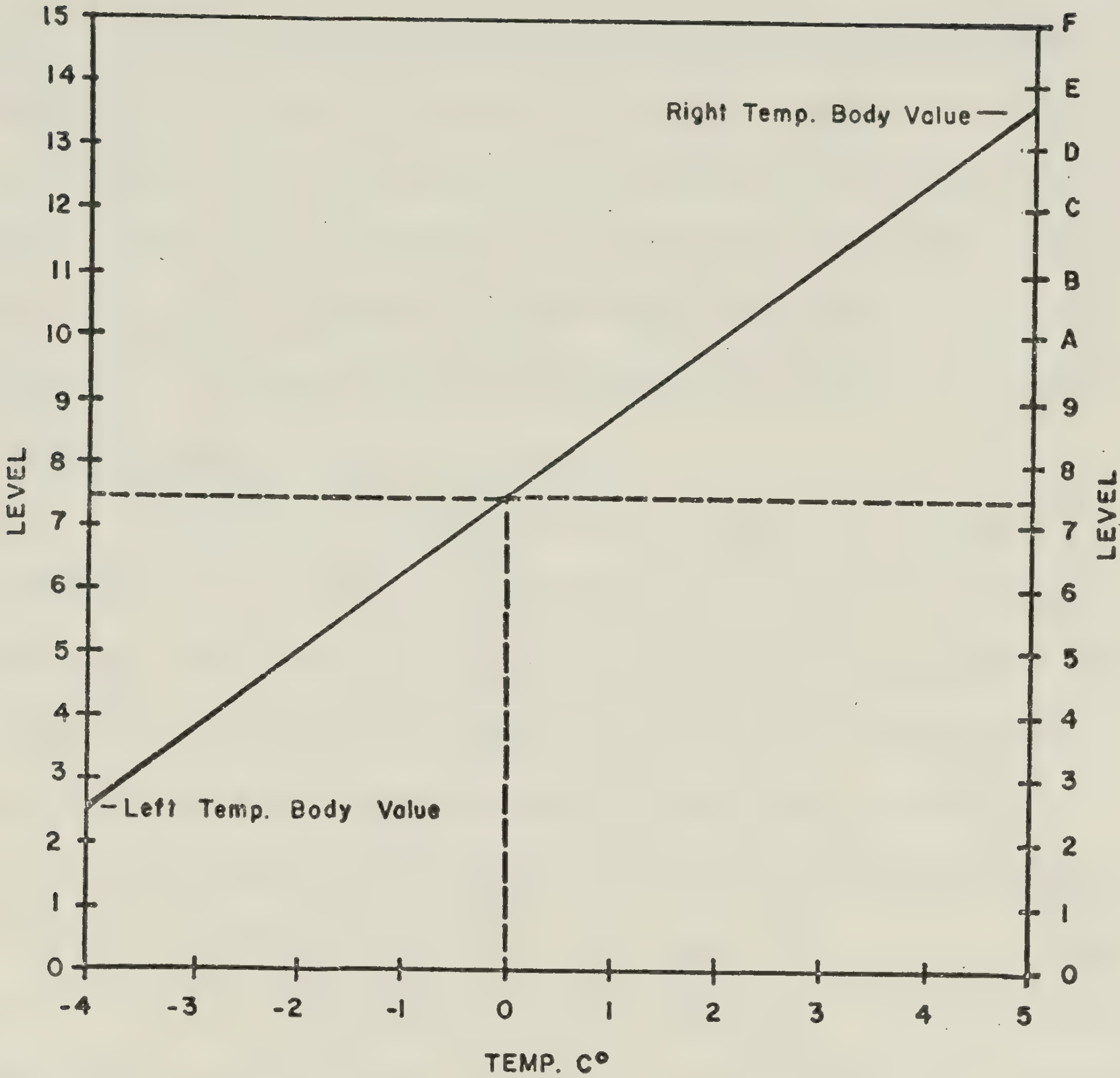


Figure 25. Thermal IR line scan temperature reference calibration chart.

$$W = \sigma T^4 \varepsilon$$

$$T' = (W/\sigma)\ 0.25 \qquad (7)$$

where W is the power output of a greybody in watts per cm^{-2}, ε is the emissivity factor, σ is Stephan-Boltzman's constant 5.67×10^{-12} watts per $cm^{-2}\ K^{-4}$, T is the greybody temperature in °K, and T' is the blackbody temperature in °K.

In order to demonstrate a possible use of these normalizing calculations, several assumptions must be made. The emissivities are assumed to be those found in Table 3 (Hudson, 1969) and the atmospheric losses are ignored.

TABLE 3

Material	Emissivity
Lacquer, black	0.97
Soil, dry	0.92
Soil, saturated	0.95
Water	0.96
Wood	0.90

Because the scanner's temperature calibration plates (black lacquer) have an emissivity of 0.97 and their real temperature is obtained from thermocouples within the plate, the scanner sees them as 2.04°C colder (cold body, -4°C) and 2.11°C colder (warm body, 5°C) respectively, than the thermocouple measurements. Thus, for each greybody temperature that we calculate, a value of approximately

2.07°C must be added after calculation of T' using Eq. 7; this addition of the correction factor cancels the reading error in the black body temperature reference. The lake returned an apparent temperature of 5°C which was adjusted downward by 0.7°C (calculated from Eq. 7 and corrected to proper black body readings). Similarly, the road which was assumed to be saturated soil was adjusted downward 1.2°C to read 0°C, and the hygrothermograph site which is a slashed area covered by cut wood had its apparent temperature adjusted downward 5°C to read -5°C. Thus, the ground temperature was about 6°C colder than the hygrothermograph that reported 0°C to 1°C at 6 inches above the ground at the time of the flight.

The above corrections were too large because of the assumption that atmospheric losses were negligible. If suitable profiles of atmospheric humidity and temperature were available, the real temperatures could be adjusted upwards to approximate the actual surface temperatures more accurately. Obtaining the real temperature from the thermal IR scanner, however, is only a first step of a long development that must be undertaken before the scanner can achieve its full potential.

CHAPTER V

CONCLUSION

Remote sensing in terms of rapid survey of large areas has been presented within this thesis as the detection of radiant energy within several portions of the electromagnetic spectrum. It is not clearly stated in many sources what the sensors actually measure. The present sensors never have and never will tell us anything more than the radiant power intensity at the entrance to the optics. What this means for users is that there is a very long inferential chain between what the sensors measure and what one is interested in. They do not even tell us directly the reflectivity and emissivity. There is a large job ahead in making the connection between the sensors and the things one is interested in measuring.

For example, agriculturalists are interested in crop yield which is strongly related to plant vigor. The sensors show radiant power. The conversion of radiant power to vigor to crop yield is a problem that at present is lacking an answer. The breakthroughs in remote sensing are not going to be made in the field of developing better sensors. We have better sensors than we know how to use today. The breakthroughs must come in understanding what features in the sensed radiation will allow diagnostic judgements about the observed materials. The connection between emissivities and reflectivities and crop species or its state of health are not well understood.

When the sensor looks at the ground the return is from a large number of various objects each having its own characteristics. By using spectrometers to measure the response of pure materials a base can be established to allow expansion into the real world where the signal is a combined return of many pure substances. Thus, remote sensing requires investigators who are primarily experts within their particular field and secondly, have an interest in remote sensing.

Remote sensing is then something more than the possession of a new set of eyeballs with the combined effect of having and properly using a large number of more or less modern technologies, the knowledge built up of relationships in the real world, the computers and their related software, and the processing methodology of handling large amounts of data. When one puts all this together, a major breakthrough in remote sensing will have been made.

Such a system does not exist today; some pieces of it do. For instance, the programs presented in the previous chapter indicate a start in the data handling field. The next step would be the application of the principles presented here to a series of specific problems in an attempt to understand the relationship between values such as vigor to the physical reflectance and emissivity of a properly instrumented ecological system.

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